United States
Environmental Protection
Agency

Office Of Water
(4204)

EPA 832 R-92-002
September 1992

EPA

Sequencing Batch Reactors For Nutrification And Nutrient Removal

Printed on Recycled Paper

U.S. Environmental Protection Agency
Office of Water Enforcement and Compliance
Washington, D.C. 20460

SEQUENCING BATCH REACTORS FOR NITRIFICATION AND NUTRIENT REMOVAL

SEPTEMBER 1992

NOTICE

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EXECUTIVE SUMMARY

Background and Objectives

The U.S. Environmental Protection Agency (USEPA) has supported new developments in wastewater treatment to promote the evolution of more efficient treatment techniques. Programs within the Office of Wastewater Enforcement and Compliance (OWEC) allow the application of new technology developments before adequate field evaluations have been completed. This support of full scale applications of new technologies without the benefit of long term evaluation comes with inherent potential risk of O&M and process problems due to lack of experience. Evaluation of new technologies seeks to determine performance capabilities and to identify weaknesses, limitations in use, maintenance shortcomings, and cost effectiveness.

OWEC evaluates certain technologies to verify overall performance and application to specific treatment needs. Results of evaluations may indicate the limitations of a technology for further consideration and support. Where technologies are successful and show beneficial applications, the USEPA is interested in providing current information to encourage their use.

This report specifically addresses the use of Sequencing Batch Reactors (SBRs) for nitrification and nutrient removal. Although limited use of SBRs began in the 1960s, it was not until the early 1980s that the technology became more widely accepted and used. After early acceptance and use, USEPA expressed increased interest in this technology especially in the comparative costs and performance.

The USEPA funded a development project in 1980, conducted by the University of Notre Dame, to evaluate batch treatment of municipal wastewater. The project involved the conversion of an existing 0.4 MGD continuous flow activated sludge facility at Culver, Indiana into a two-tank SBR.(1) Results of this 20-month project led to the use of SBR technology at several other municipal facilities. An important factor in the recent development of SBRs was the advent of more reliable instrumentation combined with microprocessor control.(2)

Recently, concern over nutrient discharges to natural water systems and more stringent regulations has led to modifications in SBR systems to achieve nitrification, denitrification, and biological phosphorus removal. Presently, approximately 170 SBRs are operating in the U.S. Of these, approximately 40 were designed specifically to include nutrient removal.

In putting together this report, information was compiled from the literature, equipment manufacturers, and wastewater treatment plant personnel. The study focused on well established plants that had nutrient data available. There are few plants with total nitrogen or phosphorus permit limits so the data for these nutrients are limited.

Findings

Sequencing Batch Reactors are designed for biochemical oxygen demand (BOD) and total suspended solids (TSS) removal from typical domestic wastewater for small (<5 MGD) municipal and private installations. Modifications to the basic design can be made to allow nitrification, denitrification, and biological phosphorus removal to occur. Cycle time, design parameters, and equipment vary among manufacturers. Influent wastewater characteristics, effluent requirements, and site specific conditions influence design development.

Data were collected from 19 municipal and private SBR wastewater treatment plants in the United States. The average design flow for these plants ranged from 0.028 to 3.0 MGD. The average mixed liquor suspended solids (MLSS) concentration for eight of the plants ranged from 2000 to 3600 mg/l. The food to mass ratio (F/M), available for six plants, ranged from 0.01 to 0.09 lb BOD/lb MLSS-day. The solids retention time (SRT) was available for two plants, which were designed for nitrification, denitrification, and biological phosphorus removal. The SRT for these two plants ranged from 17 to 30 days.

The average effluent BOD concentration ranged from 3.0 to 14.0 mg/l with removals ranging from 88.9 to 98.1 percent. The average effluent TSS ranged from 3.7 to 20.2 mg/l, excluding one plant with an average effluent TSS of 52 mg/l. No influent TSS data was available for this plant. Removals for TSS ranged from 84.7 to 97.2 percent.

Eight plants measured both influent and effluent ammonia-nitrogen (NH_3-N) concentrations. Effluent NH_3-N concentrations for these eight plants ranged from 0.285 to 1.68 mg/l. Ammonia removal ranged from 90.8 to 96.8 percent.

Denitrification data was limited. One plant monitored both influent and effluent total nitrogen concentrations. Total nitrogen removal for this plant averaged 56 percent. Denitrification was occurring at three additional plants that measured both effluent nitrate-nitrite nitrogen (NO_3 + NO_2-N) and influent NH_3-N.

Seven plants measured effluent phosphorus concentrations. The average effluent phosphorus concentrations ranged from 0.53 to 4.27 mg/l. Two plants measured both influent and effluent phosphorus concentrations. One of these plants average 57 percent phosphorus removal, while the other averaged 64 percent removal in the summer and 69 percent in the winter. Two plants added chemicals for phosphorous removal and are not included in these findings.

Conclusions

The SBR performance data shows that typical SBR designs can meet effluent BOD and TSS concentrations of less than 10 mg/l. With some additional design modifications, SBRs can successfully nitrify to limits of 1 to 2 mg/l NH_3-N. They also appear to achieve denitrification when properly designed and achieve phosphorus removal without chemicals to less than 1.0 mg/l, although data on both processes are limited.

SBR's flexibility to meet changing influent conditions due to ability to adjust cycles can be especially important for biological nutrient removal design and process optimization. Current SBR designs are typically very conservative with long HRTs, low F/Ms and high MLSS.

SBR aeration design is different from a conventional activated sludge system, since all the process air must be supplied during the FILL and REACT cycles. Downstream processes following SBRs must be sized for higher flow rates due to high decant ratios unless flow equalization is used.

The SBR market is competitive which will encourage cost effectiveness when compared to competing technologies. State standards have not yet been developed for SBRs similar to those that many states have for conventional systems. Current designs are based on several factors, including fundamental process knowledge, manufacturer's information, actual plant performance experience, and permit requirements.

SEQUENCING BATCH REACTOR FACT SHEET

Description - A sequencing batch reactor (SBR) is an activated sludge biological treatment process that is applicable to treatment of municipal and industrial wastewater for small to medium flowrates (0 to 5 mgd). An SBR treatment cycle consists of a timed sequence which typically includes the following steps: FILL, REACT, SETTLE, DECANT, IDLE. When biological nutrient removal (BNR) is desired, the steps in the cycle are adjusted to provide anoxic or anaerobic periods within the standard cycles.

Aeration in an SBR may be provided by fine or coarse bubble diffusers, floating aerator/mixers or jet aeration devices. The SBR process is usually preceded by some type of preliminary treatment such as screening, communition or grit removal. Because the SBR process operates in a series of timed steps, reaction and settling can occur in the same tank, eliminating the need for a final clarifier.

The SBR technology has the advantage of being very flexible in terms of matching react and settle times to the strength and treatability characteristics of a particular waste stream.

Common Modifications - SBRs can be modified to provide secondary, advanced secondary treatment, nitrification, denitrification and biological nutrient removal. SBR manufacturers have adapted the sequence of batch treatment cycles described above in various ways. Some systems use a continuous inflow and provide a baffle to minimize short-circuiting. SBRs were originally configured in pairs so that one reactor was filling during half of each cycle (while the wastewater in the other reactor was reacting, settling and being decanted). The modified configurations available include one SBR with an influent surge/holding tank; a three SBR system in which the fill time is one third of the total cycle time; and a continuous inflow SBR.

Technology Status - There are currently (July 1991) approximately 170 wastewater treatment facilities in the United States which employ the SBR technology. Approximately 40 of these SBR systems are designed or operated for BNR.

Typical Equipment/No. of Manufacturers - Complete SBR systems are available in the United States from the following manufacturers:

Aqua-Aerobic Systems
Austgen Biojet
Fluidyne
JetTech
Purestream
Transenviro

Applications - Sequencing batch reactor technology is applicable for any municipal or industrial waste where conventional or extended aeration activated sludge treatment is appropriate. SBR sizes can range from 3,000 gpd to over 5 MGD. The technology is applicable for BOD and TSS removal, nitrification, denitrification and biological phosphorus removal. The technology is especially applicable for industrial pretreatment and for smaller flow (< 1.0 MGD) applications as well as for applications where the waste is generated for less than 12 hours per day.

Limitations - SBRs require oversize effluent outfalls because the entire daily wastewater volume must be discharged during the decant period(s), which is typically 4 to 6 hours per day. Aeration systems must be sized to provide the total process air requirements during the AERATED FILL and REACT steps. The cost-effectiveness of SBRs may limit their utility at design flow rates above 10 MGD. Earlier SBRs experienced maintenance problems with decant mechanisms but these have largely been resolved with present-day designs.

Performance - The average performance based on data from 19 plants is summarized below:

BOD Removal	89 - 98%
TSS Removal	85 - 97%
Nitrification	91 - 97%
Total Nitrogen Removal	>75 %
Biological Phosphorus Removal	57 - 69%

Chemicals Required - Chlorination and dechlorination chemicals are required for applications which involve the direct discharge of domestic waste (unless UV disinfection is utilized). Also, some facilities have found it necessary to add alum or ferric chloride to meet stringent effluent phosphorus limits.

Residuals Generated - Secondary sludge is generated at quantities similar to the activated sludge process depending on the system operating conditions (SRT and organic load).

Design Criteria

BOD Loading:	30 to 60 lbs BOD/1000 ft^3/day
SRT:	5 to 30 days
Detention time:	6 to 12 hours
F/M:	0.05 to 0.5 lbs BOD/lb MLSS
Cycle time (conventional):	4 to 6 hours
Cycle time (BNR):	6 to 8 hours

Unit Process Reliability - Tables FS-1 and FS-2 indicate the percent of time when the summer and winter monthly average effluent concentration of the given pollutants met the criteria shown in the first column. These tables were developed from the data discussed in the performance section of this sheet, although some start-up data was eliminated.

Environmental Impact - Solid waste, odor and air pollution impacts are similar to those encountered with standard activated sludge processes.

Toxics Management - The same potential for sludge contamination, upsets and pass-through of toxic pollutants exists for SBR systems as with standard activated sludge processes.

TABLE FS-1. SBR UNIT RELIABILITY - SUMMER
Monthly Average Data - April through September

	BOD mg/l	TSS mg/l	TKN mg/l	NH_3-N mg/l	NO_3+NO_2-N mg/l	P mg/l	TN mg/l
<.5 mg/l	0.0%	0.0%	16.7%	42.6%	6.7%	24.4%	0.0%
<1 mg/l	0.0%	0.0%	16.7%	61.7%	53.3%	53.7%	0.0%
<2 mg/l	1.4%	2.1%	16.7%	77.4%	68.9%	78.0%	0.0%
<3 mg/l	14.4%	7.6%	16.7%	87.8%	75.6%	82.9%	0.0%
<4 mg/l	26.7%	16.7%	16.7%	91.3%	91.1%	85.4%	0.0%
<5 mg/l	34.9%	25.0%	83.3%	92.2%	93.3%	95.1%	0.0%
<10 mg/l	69.9%	61.8%	83.3%	98.3%	97.8%	100.0%	25.0%
<20 mg/L	96.6%	88.2%	83.3%	100.0%	97.8%	100.0%	75.0%
<30 mg/l	98.6%	93.8%	100.0%	100.0%	97.8%	100.0%	91.7%
# Plants	14	14	1	11	5	5	1

Data taken from the following 15 wastewater treatment facilities:
Armada, MI; Buckingham, PA; Caledonia, MN; Del City, OK; Dundee, MI; Grafton, OH; Manchester, MI; McPherson, KS; Southeast WWTP, Conover, NC; Walnut Grove, Stroudsburg, PA; Chateau Estates, Clarkston, MI; Clover Estates, Muskegon Heights, MI; Grundy Center IA; Mifflinburg, PA; and Windgap, PA.

TABLE FS-2. SBR UNIT RELIABILITY - WINTER
Monthly Average Data - October through March

	BOD mg/l	TSS mg/l	TKN mg/l	NH_3-N mg/l	NO_3+NO_2-N mg/l	P mg/l	TN mg/l
<.5 mg/l	0.0%	0.0%	0.0%	45.5%	25.5%	24.6%	0.0%
<1 mg/l	0.0%	0.0%	0.0%	65.2%	61.7%	50.8%	0.0%
<2 mg/l	0.7%	2.0%	0.0%	76.8%	68.1%	80.3%	0.0%
<3 mg/l	12.2%	7.4%	0.0%	82.1%	78.7%	86.9%	0.0%
<4 mg/l	23.7%	16.8%	0.0%	83.0%	89.4%	93.4%	0.0%
<5 mg/l	35.3%	20.8%	0.0%	86.6%	89.6%	96.7%	0.0%
<10 mg/l	65.5%	55.0%	0.0%	92.6%	95.7%	100.0%	38.5%
<20 mg/L	89.2%	82.6%	100.0%	100.0%	100.0%	100.0%	100.0%
<30 mg/l	95.7%	90.6%	100.0%	100.0%	100.0%	100.0%	100.0%
# Plants	14	14	1	11	5	5	1

Data taken from the following 15 wastewater treatment facilities: Armada, MI; Buckingham, PA; Caledonia, MN; Del City, OK; Dundee, MI; Grafton, OH; Manchester, MI; McPherson, KS; Southeast WWTP, Conover, NC; Walnut Grove, Stroudsburg, PA; Chateau Estates, Clarkston, MI; Clover Estates, Muskegon Heights, MI; Grundy Center IA; Mifflinburg, PA; and Windgap, PA.

Flow Diagram - Figure FS-1 illustrates a typical SBR over one cycle.

Costs - July 1991 dollars, ENR (Engineering News Record) Index. Construction costs were available for six plants, while five plants supplied total capital costs. Construction costs were converted to capital costs by adding 15 percent for engineering and construction supervision and 15 percent for contingencies. All capital costs were adjusted to July 1991 costs. Figure FS-2 presents the cost data available for utility, operating and capital costs compared to actual and design flow.

References

Evaluation of Sequencing Batch Reactors for Nitrification and Nutrient Removal. Prepared by HydroQual, Inc., October 1991.

Sequencing Batch Reactors - Summary Report (EPA 625/8-86/011) U.S. Environmental Protection Agency, Center for Environmental Research Information, Cincinnati, Ohio

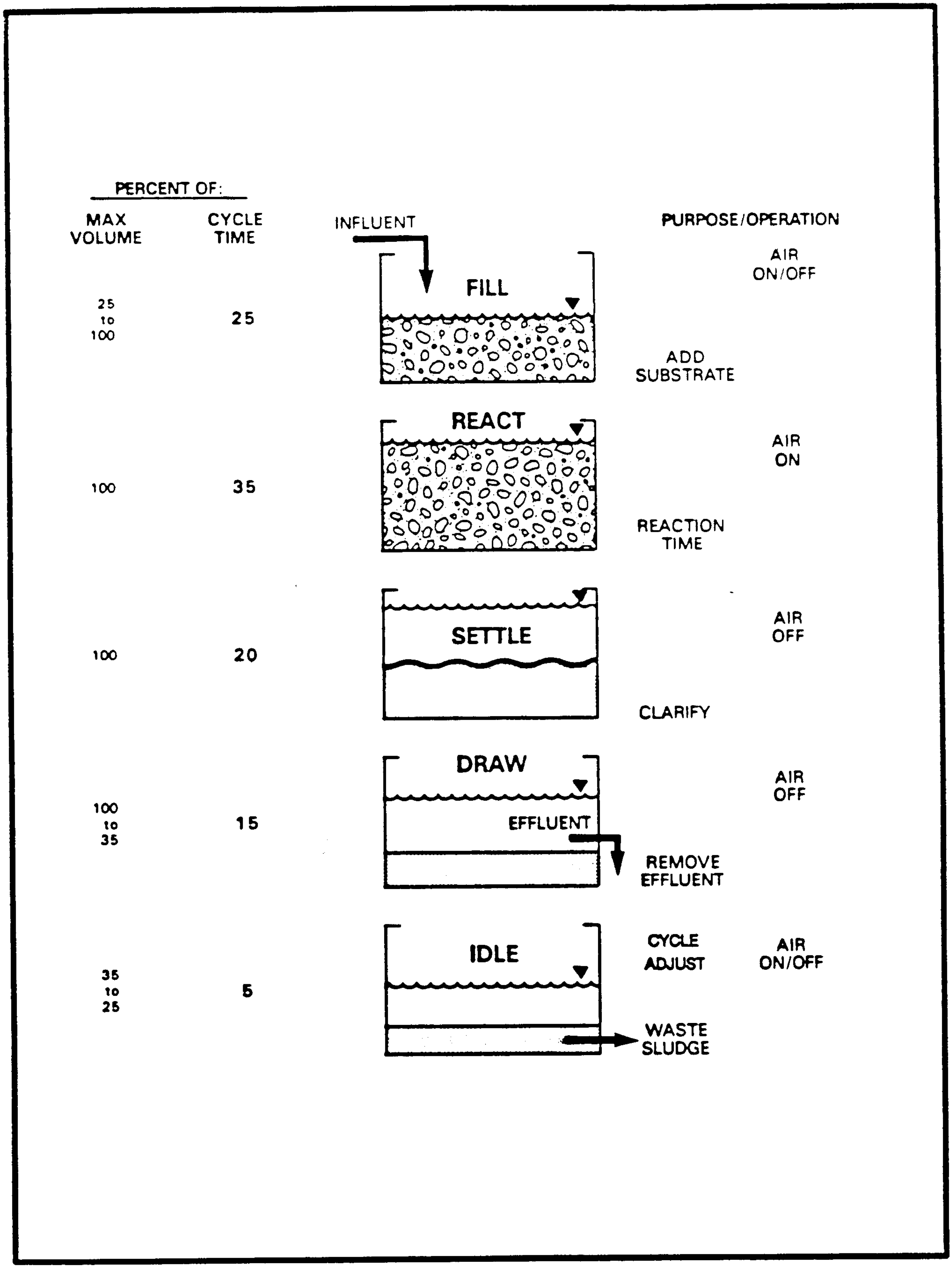


Figure F-1. Typical SBR Operation for One Cycle

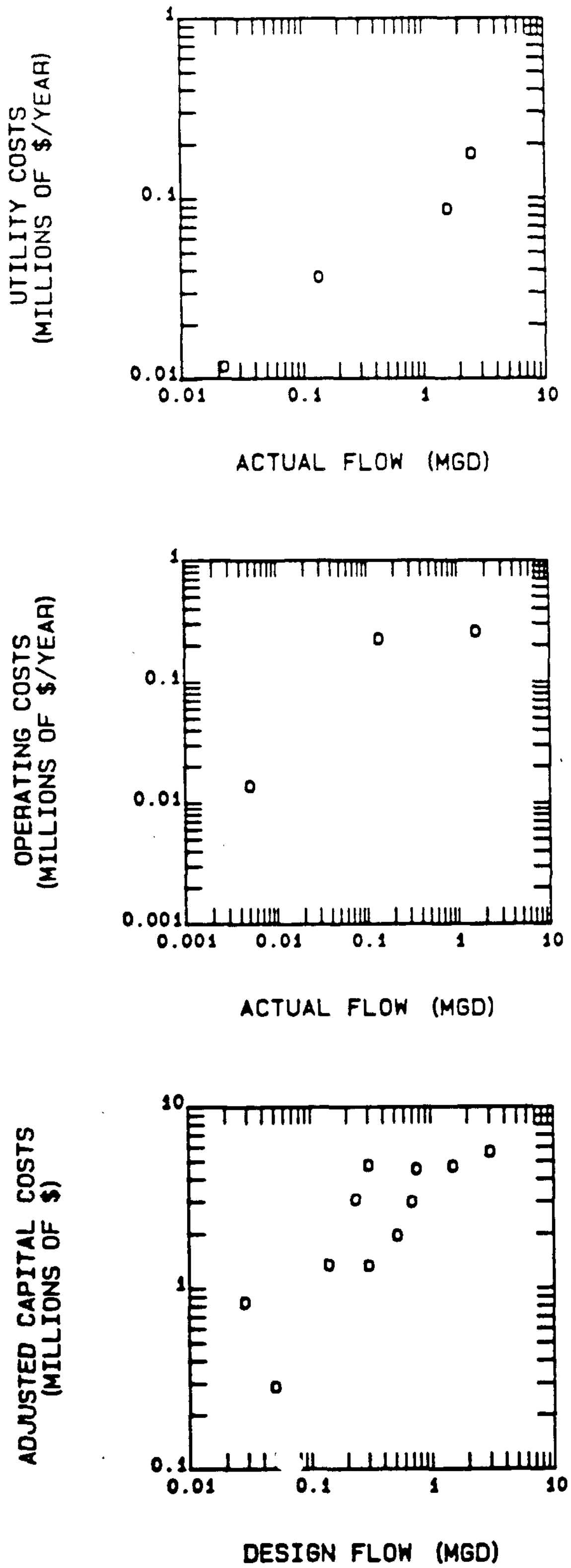


Figure F-2. Utility, Operating and Capital Costs

SECTION 1.

DESCRIPTION OF SBR PROCESS

INTRODUCTION

The SBR is a modification of conventional continuous flow activated sludge sewage treatment. The SBR is a fill-and-draw system that operates in a batch rather than in a continuous mode. A conventional activated sludge (CAS) system carries out aeration and sedimentation/clarification simultaneously in separate tanks. The SBR process performs these operations sequentially in the same tank. An SBR system is comprised of either a storage tank and an SBR tank, or a minimum of two SBR tanks to handle continuous influent. A modification of the SBR process, the Intermittent Cycle Extended Aeration System (ICEAS^R), manufactured by Austgen Biojet, operates with a continuous feed and intermittent withdrawal. A baffle wall installed in the ICEAS^R treatment tank buffers this continuous inflow.(3)

Cycle Operation

A typical SBR cycle for BOD and TSS (Total Suspended Solids) removal is divided into the following five steps:

1. Fill - Raw wastewater flows into the tank and mixes with mixed liquor held in the tank. Aeration is on and biological degradation begins to take place.

2. React - The mixed liquor is aerated for a specified time until the design effluent BOD is reached.

3. Settle - Aeration is stopped and the solids settle to the bottom of the tank.

4. Draw - Treated effluent is decanted from the top of the tank and discharged.

5. Idle - Time between cycles. Idle is used in multiple tank configurations to adjust cycle times between SBR reactors. Sludge wasting can occur during idle, draw or settle. Differences in fill time may exist due to diurnal fluctuation. Other minor variations in individual SBR tank cycles are regulated with the idle step.

Figure 1 illustrates this sequence of events.[4] The ICEAS® modification does not have a separate idle or fill phase since it uses continuous fill. The baffled pre-reaction compartment in an ICEAS® tank permits wastewater to enter continuously without causing a significant disturbance during settle and draw. Figure 2 illustrates the ICEAS® tank configuration.[3]

DESCRIPTION OF EQUIPMENT

The SBR system consists of one or more tanks equipped with a reactor inlet, aeration equipment, a sludge draw off mechanism, a decant mechanism for removing clarified supernatant, and a control mechanism to time and cycle the processes. Tanks may be constructed of steel or concrete. The shape is not critical and SBRs can be retrofitted into existing rectangular or circular tanks.

SBR manufacturers offer a variety of features designed to meet different performance needs. Decant mechanisms and air diffuser designs may differ markedly between manufacturers. Decant mechanisms include a submerged outlet pipe with automated valves, weir troughs connected to flexible couplings, floating weirs, movable baffles, tilting weirs and floating submersible pumps.[1] Some decant mechanisms have the potential problem of drawing solids when beginning the DRAW phase. Solids may get trapped on the piping during aeration. This can be minimized by decanter modifications or by recirculating the first few minutes of flow to a second reactor until the supernatant clears. It is important to insure that effluent removal is uniformly distributed across the tank; the draw mode is the peak hydraulic flow within the cycle and short circuiting can cause uncontrolled suspended solids loss.

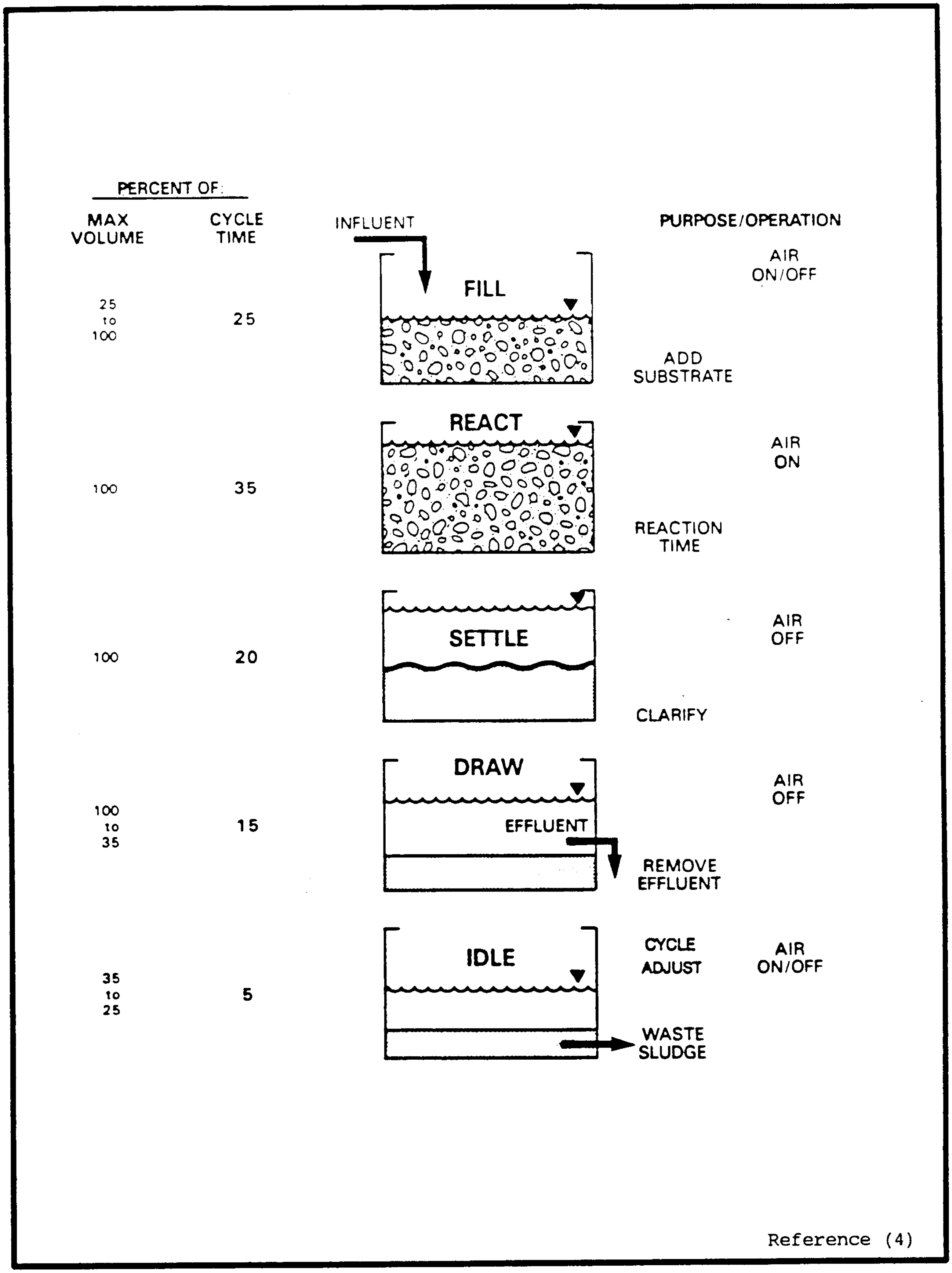
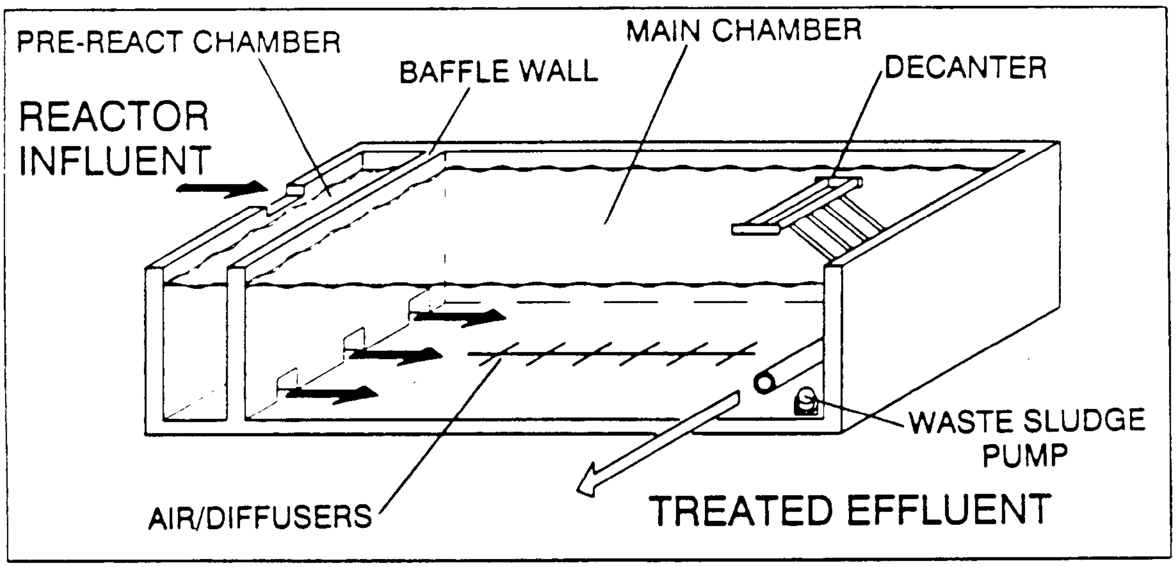


Figure 1. Typical SBR Operation for One Cycle



Reference (3)

Figure 2. Austgen Biojet ICEAS[R] Basin

Aeration systems include jet aeration, fine bubble and coarse bubble diffused aeration, and floating mechanical aerators. Jet aeration can provide either aeration or mixing without aeration in one unit by operating the pumping system with the air supply on or off. Some manufacturers supply separate mixing mechanisms for this purpose. One variation to the typical aeration system is retrievable aerators, which allow aerators to be cleaned or replaced without emptying the SBR.[7] Other systems include backflush mechanisms to clean the aerators.

Advantages

The SBR system has advantages compared to a CAS system and offers much flexibility. Some of the technical and financial advantages are:

* Early in plant lifetime, when plant flow may be significantly below design flow, level sensors that control cycle times can be set at a lower level. Cycle times would be the same as design, but power would not be wasted in over-aeration.[5]

* A greater dissolved oxygen driving gradient exists during the first part of the react cycle due to the low/zero DO concentration during anoxic fill. This results in somewhat higher oxygen transfer efficiencies for a given size of aeration equipment.[2]

* An SBR tank operates as an equalization tank during fill and can therefore tolerate peak flows and shock loads of BOD without degradation of effluent quality.

* A return activated sludge (RAS) pumping system is not needed since aeration and settling occur in the same tank. Sludge volume and sludge age are controlled by sludge wasting.

* Periodic discharge of flow may enable effluent to be held until permit limitations are met.

* Growth of filamentous organisms which cause sludge bulking can be controlled by adjustments in the food-to-mass ratio (F/M) and aeration time during the fill cycle.

* SBR systems may require less physical space than a CAS system when considering the entire plant. SBR systems can be retrofitted into a wide range of existing tank structures.

Disadvantages

The following are potential disadvantages of the SBR system. These are usually overcome through proper design, process adjustments, or equipment modifications.

* Problems with sludge settling will result in solids in the effluent and a loss of the process performance.

* Floating decant mechanisms may be subject to mechanical problems. Fixed systems require that the sludge blanket be below the intake before decanting. Both systems may draw in trapped solids when first starting the decant phase.

* Surface freezing of controls and decant mechanisms may occur in cold climates during the settling and decant phases.

* The relatively high flow rate during decant may require flow equalization or over design when followed by disinfection or filtration facilities.[6]

* With long SRTs, denitrification may occur during settle and sludge may begin to rise due to the formation of nitrogen gas. This is usually aggravated at elevated temperatures.[6]

* Aeration equipment must be larger, since process air must be supplied over a shorter period.

* Effluent sewers must be oversized since decant flows are much higher than normal inflow.

SECTION 2.

THEORY OF NITRIFICATION, DENITRIFICATION, AND PHOSPHORUS REMOVAL

The following sections describe biological processes that occur naturally in the environment and which can be encouraged to take place for the purpose of nutrient removal in wastewater treatment systems.

NITRIFICATION

Nitrification is the biological oxidation of ammonia (NH_4^+) to nitrite (NO_2^-) and then to the nitrate (NO_3^-) form. The two major species of microorganisms responsible for the biological oxidation of nitrogen compounds are the autotrophic bacteria Nitrosomonas and Nitrobacter. Nitrosomonas oxidizes ammonia to nitrite. Nitrobacter completes the nitrification process by oxidizing nitrite to nitrate.

The overall nitrification of ammonia can be expressed by the following reaction:

$$NH_4^+ + 2O_2 \dashrightarrow NO_3^- + 2H^+ + H_2O$$

Temperature, pH, dissolved oxygen concentration, and solids retention time (SRT) are important parameters in nitrification kinetics. The rate of nitrification in an activated sludge system decreases with decreasing temperature. The optimum temperature is between 25 and 35°C. The optimum pH for nitrification is in the range of 7.5 to 9.0. Below pH 7.0 and above pH 9.8 the nitrification rate is less than 50 percent of the optimum. Alkalinity is destroyed by the oxidation of ammonia, thereby reducing the pH. A ratio of 7.14 mg alkalinity is destroyed per mg of ammonia nitrogen oxidized. Aeration partially strips the carbon dioxide from the wastewater thereby reducing alkalinity reduction; however sufficient alkalinity must remain in the wastewater so as not to depress the pH. Maximum nitrification rates occur at dissolved oxygen concentrations greater than 2 mg/l. The nitrification process consumes 4.57 lbs of oxygen per pound of ammonia nitrogen converted to nitrate.[8]

The nitrification rate is also dependent on the fraction of nitrifying bacteria present in the system. A principal means of increasing the nitrification rate is to increase the fraction of nitrifiers. This can be accomplished by increasing the aeration basin mixed liquor suspended solids (MLSS) concentration which increases the SRT. Lowering the ratio between the 5-day BOD and the total Kjeldahl nitrogen concentration (BOD_5/TKN) by nitrifying in a separate second stage aeration system would also increase the percentage of nitrifiers and thus the nitrification rate.(8) This approach, however, has not been found to be a cost effective design for normal municipal wastewater.

DENITRIFICATION

Biological denitrification is a process in which nitrate is reduced to nitrogen gas by microorganisms in the absence of dissolved oxygen. Denitrification can occur provided a sufficient source of nitrate and organic carbon are present. The denitrification process can be expressed by the following reaction:

$$NO_3^- + \text{organic carbon} \dashrightarrow N_2(\text{gas}) + CO_2$$

The denitrification process occurs in two steps. The first step involves the reduction of nitrate to nitrite. In the second step nitrite is reduced to produce nitrogen gas. Numerous species of facultative heterotrophic bacteria, including Pseudomonas, Micrococcus, Achromobacter, and Bacillus are capable of converting nitrate to nitrogen gas. Nitrate replaces oxygen in the respiratory processes of the organisms capable of denitrification under anoxic conditions.(8)

Environmental factors including temperature, pH, and dissolved oxygen concentration have an effect on the rate of denitrification. Denitrification occurs at temperatures in the range of 10 to 30°C. The rate of denitrification is reduced below pH 6.0 and above pH 9.0. The optimum pH is in the range of 6.5 to 8.0. A dissolved oxygen concentration greater than 1 mg/l inhibits denitrification.

PHOSPHORUS REMOVAL

Phosphorus in wastewater may be present as orthophosphate, polyphosphate, or organic phosphorus. Orthophosphate is the more easily removed of the three types of phosphorus. Polyphosphates are converted to orthophosphate by hydrolysis and organic phosphorus is converted to orthophosphate through bacterial decomposition.[9]

Conventional secondary biological treatment systems accomplish partial phosphorus removal by using phosphorus for biomass synthesis during BOD removal. A typical phosphorus content of microbial solids is 1.5 to 2 percent based on dry weight. Wasting of excess microbial solids may result in a total phosphorus removal of 10 to 30 percent, depending on the BOD to phosphorus ratio, the system sludge age, sludge handling techniques and sidestream return flows.[9]

Additional biological phosphorus removal will occur if wastewater is subjected to both anaerobic and aerobic conditions. When an anaerobic stage (absence of DO and oxidized nitrogen) precedes an aerobic stage, fermentation products are produced from the BOD in the wastewater by the action of facultative organisms. The phosphorus storing microorganisms are able to assimilate the fermentation products under anaerobic conditions. Because many competing microorganisms cannot function in this manner, the phosphorus storing microorganisms have a distinct advantage over other organisms in the activated sludge system. Thus, the anaerobic phase results in the development of phosphorus storing microorganisms.[9,10]

During the aerobic phase the stored substrate products are depleted and soluble phosphorus is taken up by the microorganisms in quantities greater than what is needed to function. This "luxury uptake" of phosphorus is maximized at dissolved oxygen concentrations greater than 2 mg/l. At lower DO concentrations the excess phosphorus will be released from the microorganisms.

For biological phosphorus removal to occur, an anaerobic stage is required for the production of the fermentation products. Therefore, if nitrification is occurring, it is necessary for denitrification to take place before enhanced biological phosphorus removal can occur. If this does not happen and nitrite or nitrate are present, the system is anoxic rather than anaerobic. For this reason, a low dissolved oxygen concentration must be maintained for a longer period when biological phosphorus removal is required than when denitrification is required.

SECTION 3.

DESIGN

INTRODUCTION

Standard SBR systems are designed to reduce the BOD and TSS concentrations of the wastewater. SBR systems have been consistently able to achieve removals of greater than 90 percent of BOD and TSS.

An SBR system can be designed to achieve nitrification, denitrification, and biological phosphorus removal. Adjustments to the standard operating strategies are required. These adjustments may require additional plant capacity and equipment, and are included in the design of a system.

Cycle times are an essential aspect of an SBR system design. The basic steps in an SBR cycle, FILL, REACT, SETTLE, DRAW, and IDLE, vary both by manufacturer and design conditions. Total cycle times may be constant or may vary with flow. The percent of the reactor volume that is decanted during each cycle (percent decant) is a design parameter important to batch systems. The size of the reactor volume is determined by design flow requirements, the design volume occupied by settled MLSS, and a design decant depth. SBR designs are unique because the oxygen delivery system must be sized to deliver the total process oxygen requirements during the FILL and REACT portions of the SBR cycle.[4]

In a multi-tank system, air piping may be arranged so that one blower can aerate more than one reactor. Table 1 shows the sequence of events in a three-tank system which offsets the REACT phase in each basin.[1]

Other important SBR design criteria are similar to those used in the design of a conventional activated sludge treatment facility. These include hydraulic retention time (HRT), solids retention time (SRT), MLSS concentration, influent wastewater characteristics, and effluent requirements.

Table 1. Sequence of Events in a Three Tank System

Tank Number		
1	2	3
		Settle
Fill	React	
		Draw
		Idle
	Settle	
React		Fill
	Draw	
	Idle	
Settle		
	Fill	React
Draw		
Idle		
		Settle
Fill	React	
		Draw
		Idle
	Settle	
React		Fill
	Draw	
	Idle	
Settle		
	Fill	React
Draw		
Idle		

Reference (1)

The following two sections examine SBR designs for BOD and TSS removal with nitrification and the variations to these designs necessary to achieve denitrification and phosphorus removal.

STANDARD SBR DESIGNS WITH NITRIFICATION

A standard SBR system is designed to reduce the BOD and TSS concentrations of a wastewater. Some standard systems are designed for nitrification as well. Table 2 lists typical steps for a standard SBR cycle with nitrification. This table also describes the purpose of each step and the conditions that should be present to best achieve that purpose. Nitrification can only occur under conditions of adequate DO (minimum 1 to 2 mg/l) and sufficiently long SRT (5 to 20 days or more depending upon temperature) to ensure growth of nitrifying bacteria. In an SBR system, nitrification takes place during the REACT phase and periods of aerated fill.[4,7]

The cycles designed by the majority of the SBR manufacturers studied deviate from the standard cycle of Table 2 in one or more ways. Other differences occur in tank configuration and design parameters. The following paragraphs briefly discuss specific designs of six major SBR manufacturers.

Aqua-Aerobic Systems

Aqua-Aerobic's tankage and total cycle times are designed to treat the maximum daily flow. This is to ensure that effluent quality is maintained during periods of peak flows. Typically, other manufacturers design a shorter storm cycle to handle peak flows during rain events that may reduce effluent quality if operated for extended periods. A larger SBR tank is required for systems designed for the maximum daily flow.

Aqua-Aerobics conventional load system provides for BOD and TSS removal and limited nutrient reduction. The system operates at an F/M ratio of 0.15 to 0.35 lb BOD/lb MLSS-day and a MLSS between 1500 and 3000 mg/l.

TABLE 2. TYPICAL CYCLE FOR A STANDARD SBR WITH NITRIFICATION

Step	Conditions	Purpose
FILL	Influent flow into SBR Aeration Time = half of cycle time	Addition of raw wastewater to the SBR, BOD removal and nitrification
REACT	No influent flow to SBR Aeration Time typically = 1 to 2 hours (varies widely depending on BOD removal kinetics and waste strength	Biological BOD removal and nitrification
SETTLE	No influent flow to SBR No aeration Time = approx. 1 hour (depends on settling characteristics)	Allow suspended solids to settle, yielding a clear supernatant
DRAW	No influent flow to SBR No aeration Effluent is decanted Time = 1 hour (varies)	Decant - remove effluent from reactor; 10 to 50 percent of the reactor volume is typically decanted, depending on hydraulic considerations and SBR manufacturer's design
IDLE	No influent flow to SBR No aeration Sludge is wasted Time = variable, determined by flow rate	Multi-tank system, allows time for one reactor to complete the fill step before another starts a new cycle. Waste sludge - remove excess solids from reactors

A typical total cycle time is 4 to 6 hours

The SBRs designed by Aqua-Aerobics typically include a separate mixing device. In addition, Aqua-Aerobics offers both fixed and retrievable diffusers.[7]

<u>Austgen Biojet</u>

The Austgen Biojet ICEAS(R) SBR system utilizes continuous inflow and therefore does not require a separate FILL step. Continuous inflow also eliminates the need for an IDLE step. Sludge is wasted during the SETTLE or DRAW phase. The SBR basin includes a baffle wall that forms a pre-react zone which has an anoxic environment during SETTLE and DRAW. The SBR basin is typically designed with a length to width ratio of at least 3:1. This creates a plug flow system and prevents short-circuiting of the influent during the decant sequence.

An Austgen Biojet ICEAS(R) SBR is typically designed to aerate for two hours within a total cycle time of four hours. Overall cycle times are shorter than other system due to the lack of a separate FILL step. Austgen Biojet systems may also be designed with one hour aeration and a three-hour cycle to handle storm flows.

If only BOD and TSS removal are required, the reactor size for an Austgen Biojet SBR is determined by using a prescribed food to microorganism (F/M) ratio. A F/M ratio between 0.05 and 0.15 lb BOD/lb MLSS-day is typically used. If nitrification is required, the determination of the reactor volume required for nitrification is based on the required degree of ammonia removal, the nitrification rate, the time of aeration, and the mixed liquor volatile suspended solids (MLVSS) concentration. When both BOD removal and nitrification are required, the reactor volumes required for BOD removal and nitrification are determined, and the larger of the two is chosen.[3]

<u>Fluidyne</u>

For small systems, Fluidyne will design a single SBR with continuous inflow, rather than the standard sequencing reactor. In SBRs with continuous inflow, the tank is baffled to minimize short-circuiting and there is no discrete FILL step. Fluidyne also designs single- or multi-reactor SBR systems without continuous inflow. Each Fluidyne SBR tank is equipped with jet aerators that can provide both aerobic oxidation and anoxic mixing.(11)

JetTech

Design information was not available from the manufacturer. Limited information was available from the operators of various JetTech SBR systems. Based on this information, a standard JetTech cycle appears to be very similar to the cycle described in Table 2. JetTech does include an additional BACKFLUSH step that lasts approximately five minutes and serves to clean out the aeration system. JetTech systems are often, though not exclusively, equipped with jet aerators.(12)

Purestream

Purestream typically designs small to medium size SBR systems to treat private and industrial wastewaters. Purestream SBR designs are similar to the cycle shown in Table 2 but may include an IDLE step to coordinate the cycles for two sequencing reactors or to increase the design safety factor. The length of the REACT step in a Purestream design is determined from BOD removal, nitrification and denitrification kinetics. Purestream designs SBR systems with coarse bubble, diffused air and air lift multiple point decant systems. Their standard design includes duplicate aeration, air lift decant and sludge wasting capability.(5)

Transenviro

Nearly all Transenviro SBR systems are designed for biological nutrient removal. Transenviro chooses to design SBR systems in this manner to avoid potential settling problems that may occur in reactors without anaerobic or anoxic sequences.(13)

SBR DESIGNS FOR BIOLOGICAL NUTRIENT REMOVAL

When a wastewater treatment facility must meet phosphorus or total nitrogen limits, SBR designs become somewhat more complex. Operating strategies for nitrification and denitrification are similar for most systems. Figure 3 illustrates a typical denitrification cycle for an SBR.(1) For denitrification to occur, an anoxic period in the SBR is necessary following BOD removal and nitrification. The DO is reduced to less than 0.5 mg/l during SETTLE, DRAW, and IDLE periods.

As previously described in the theory section, biological phosphorus removal requires an anaerobic period. This step can be included in an SBR system. Table 3 lists typical steps for a SBR cycle that includes biological nutrient removal. This table also describes the purpose of each step and the conditions that should be present to best achieve that purpose. To incorporate the phosphorus removal strategy, the anaerobic period will be longer than the anoxic period required for denitrification. Two additional steps can be added to maximize phosphorus removal. The first step is a separate anaerobic period following decant which releases some phosphorus to the liquid above the sludge. This step is followed by a second decant step where supernatant with phosphorus is drawn off for separate chemical treatment, and phosphorus starved sludge is returned in the fill period. Sludge wasting occurs following the aerobic step.

In addition to the information presented in Table 3, it is essential to biological phosphorus removal that sludge be wasted under aerobic conditions. The maximum amount of phosphorus is incorporated into the sludge under aerobic conditions. For similar reasons, an aerobic digester that maintains an aerobic environment for sludge is used with the SBR plants since digestor supernatant is normally recycled.

Chemical addition for phosphorus removal is sometimes used, especially when effluent permit limitations are 2.0 mg/l or less. When properly operating, an

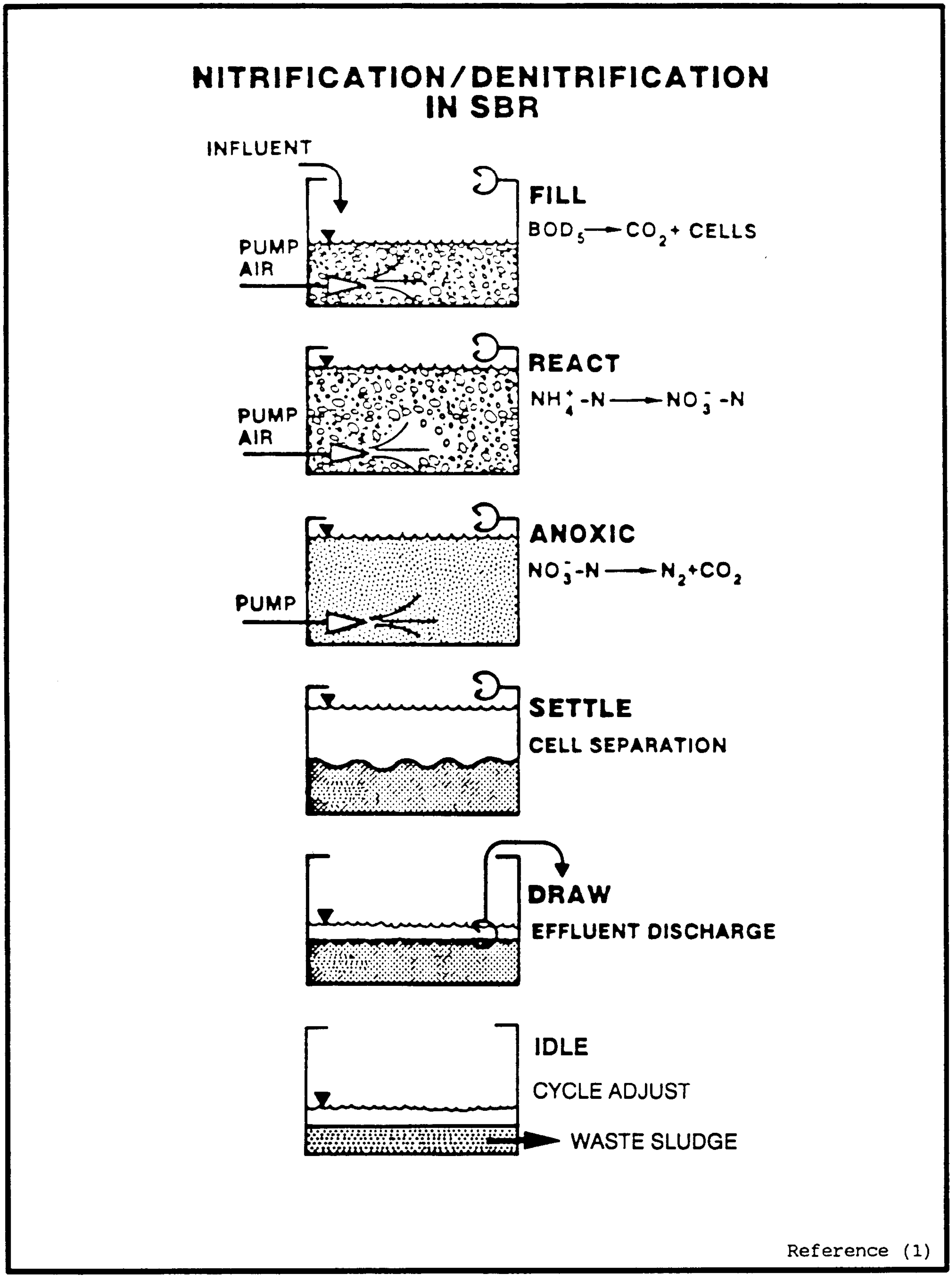


Figure 3. Denitrification Cycle for SBR

TABLE 3. TYPICAL SBR CYCLE FOR BIOLOGICAL NUTRIENT REMOVAL

Step	Conditions	Purpose
UNAERATED FILL	Influent flow into SBR No aeration Time = approximately 1.5 hours Mixed	Addition of wastewater to the SBR, continuation of anoxic or anaerobic conditions to allow denitrification and to encourage the growth of phosphorus-removing bacteria
AERATED FILL	Influent flow into SBR Aeration (DO > 2 mg/l) Time = half of the total cycle time minus the unaerated fill time	Addition of wastewater to the SBR, BOD removal and nitrification, phosphorus uptake
REACT	No influent flow to SBR Aeration (DO > 2 mg/l) Sludge may be wasted Time = typically = 1 to 2 hours (varies widely)	Biological BOD removal and nitrification, phosphorus uptake
SETTLE	No influent flow to SBR No aeration Sludge is wasted Time = approx. 1 hour	Allow suspended solids to settle to yield a clear supernatant, decrease the DO concentration to encourage denitrification; waste sludge under aerobic conditions with maximum phosphorus content
DRAW	No influent flow to SBR No aeration Effluent is decanted Time = 1 to 2 hours	Remove effluent from reactor, decrease the DO concentration further to encourage denitrification and the growth of phosphorus-removing bacteria
IDLE	No influent flow to SBR No aeration Time = 1 to 15 minutes (typically occurs during the end of the DECANT step)	Allow coordination of cycles in multi-tank system; maintain a low DO concentration to encourage denitrification and the growth of phosphorus-removing bacteria

A typical total cycle time is 6 to 8 hours

SBR can achieve high rates of biological phosphorus removal, though removal rates may decrease during periods of storm flow. Larger reactors, necessary with longer cycle times, would be required if biological phosphorus removal were utilized. The additional cost of the larger reactors, however, may be favorable compared to the cost of continuous chemical addition. This trade-off needs to be evaluated on a case by case basis during the design phase.

SBR manufacturers typically offer systems that incorporate nutrient removal and deviate in one or more ways from the cycle described in Table 3. The following paragraphs summarizes the biological nutrient removal designs for six major SBR manufacturers.

<u>Aqua-Aerobic Systems</u>

Aqua-Aerobic's low load system provides for BOD and TSS removal and nitrogen and phosphorus reduction and operates at a F/M ratio of 0.05 to 0.10 lb BOD/lb MLSS-day and a MLSS between 3500 and 5000 mg/l.(7)

<u>Austgen Biojet</u>

Austgen Biojet's ICEAS^R design does not utilize a separate UNAERATED FILL or AERATED FILL step due to continuous inflow. Instead, Austgen Biojet adds anoxic sequences to the treatment cycle by alternating aerobic and anoxic periods during the REACT step. A typical cycle design includes a two-hour REACT step with two 30-minute periods of aeration and two 30-minute anoxic periods.

When phosphorus removal to low concentrations (<1 mg/l) is required, an Austgen Biojet ICEAS^R SBR is designed with an anaerobic phase. A phosphorus removal cycle includes a four-hour REACT step consisting of four 30-minute periods of aeration and four 30-minute anoxic periods. The ICEAS^R baffled pre-react zone has an anoxic environment during SETTLE and DRAW phases.(3)

Fluidyne

In typical Fluidyne systems, the IDLE step is an anoxic fill period. As with standard nitrification systems, Fluidyne will occasionally recommend a single baffled SBR with continuous inflow for small systems.[11]

JetTech

Based on information supplied by operators of various JetTech SBR systems, the cycles in JetTech systems designed for biological nutrient removal appear to be very similar to the cycle described in Table 3. JetTech does include an additional BACKFLUSH step which lasts approximately five minutes and serves to clean out the aeration system. JetTech systems are often, though not exclusively, equipped with jet aerators.[12]

Purestream

Purestream cycle designs for SBR systems with biological nutrient removal do not differ significantly from the cycle described in Table 3. Cycle times are established by kinetic considerations and effluent limits.[6]

Transenviro

Transenviro utilizes a variation of the SBR process known as CASS(TM), which stands for Cyclic Activated Sludge System. This is a fill-and-draw activated sludge system which combines plug flow initial reaction conditions with complete mix operation to favor co-current nitrification-denitrification.

The CASS(TM) cycle sequence typically consists of FILL-AERATION, FILL-SETTLE, DRAW (effluent removal), and .ILL-IDLE. Depending on effluent requirements, these sequences can be adjusted to include FILL NON-REACT, FILL-MIX NON-AERATION, FILL-REACT, and REACT NO-FILL.

The CASS(TM) SBR is configured with an inlet zone referred to as a "captive selector zone". Return Activated Sludge (RAS) is continuously returned to the captive selector zone. This zone exposes the biomass to equal sequences of aerobic and anaerobic initial growth conditions. According to Transenviro, anoxic mixing is not necessary because the systems have a lower DO by design.

Transenviro normally designs dual-reactor SBR systems. They also design a four-basin system, which operates as two, two-basin systems. When designing an SBR system for a facility with a phosphorus limit, Transenviro normally includes chemical addition capability.[13] Though chemical addition may only be used in cases of storm flow or biological upset, it makes evaluation of biological phosphorus removal more difficult.

SECTION 4.

SITE VISITS

INTRODUCTION

Three municipal wastewater treatment plants with SBRs were visited to obtain detailed information on operation and performance. The three plants visited represent three different SBR manufacturers. The Marlette, Michigan SBR was manufactured by JetTech, the Grafton, Ohio SBR was manufactured by Fluidyne, and the Shelter Island, New York SBR was manufactured by Austgen Biojet. These plants were chosen because they were operating well and had available nutrient data.

PLANT OBSERVATIONS

The following sections summarize the observations made at the three plants.

Marlette, Michigan

The current Marlette, Michigan wastewater treatment plant began operations on January 1, 1990. The plant was designed for an average daily flow of 0.69 MGD. The influent flow passes through a comminutor and a grit chamber prior to primary clarifiers. The primary clarifier effluent flows to the SBRs. There are three reactor basins equipped with jet aerators, however, only two of the basins are normally used. The present organic loading to the plant is not high enough to maintain the three units. The third SBR is used as an equalization tank during rainfall events resulting in high flows. During the summer months of May through August, the SBR effluent is polished by sand beds prior to disinfection by ultraviolet light. The disinfected effluent is aerated prior to discharge to a stream. The plant effluent limits are shown in the following table.

Marlette, Michigan Plant Monthly Average Effluent Limits - mg/l				
Period	CBOD	TSS	NH_3-N	P
May - October	10	20	2	NA
November - April	15	30	No Limit	NA
Year Round	NA	NA	NA	1.0

The three SBRs were manufactured by JetTech and have a volume of approximately 0.17 million gallons each. The plant was designed for nitrification and phosphorus removal, but not for denitrification. The plant has a ferric chloride feed system for phosphorus removal that is used primarily during rain events. During dry weather operations, phosphorus is removed biologically rather than chemically.

The SBR is operated at a MLSS concentration of approximately 3600 mg/l. The MLVSS concentration is between 2000 and 2500 mg/l. The SBRs are typically operated at an F/M of 0.01 to 0.02 and at an SRT in the range of 25 to 30 days. The cycle times currently used are not significantly different from those recommended by the manufacturer. A cycle time of six hours is normally used. This cycle time includes 1 hour react, 1 hour settle, and 1 hour decant. The remaining time is for anoxic fill, aerated fill and idle. Since the system automatically compensates for flow, the time for each of these steps varies. The cycle times may be adjusted by the plant operator.

Chronological plots summarizing the monthly average flow, BOD, TSS, NH_3-N, and total phosphorus for July 1990 through June 1991 are presented in Figures 4 and 5. During the period July 1990 through June 1991, the plant operated at an average influent flow of 0.42 MGD or approximately 61 percent of design. Plant influent and effluent data were available. Primary effluent data were not available; however, plant personnel indicated that approximately 20 percent of the BOD is removed in the primary clarifiers. Based on this 20 percent removal, approximately 96 percent of the BOD entering the SBR was removed prior to discharge. Ammonia nitrogen was measured during the summer months. The influent NH_3-N concentration varied considerably from the summer of 1990 to the summer of 1991. During July through October 1990 the influent NH_3-N averaged 14.3 mg/l and during May and June 1991 the influent NH_3-N averaged 1.7 mg/l. A

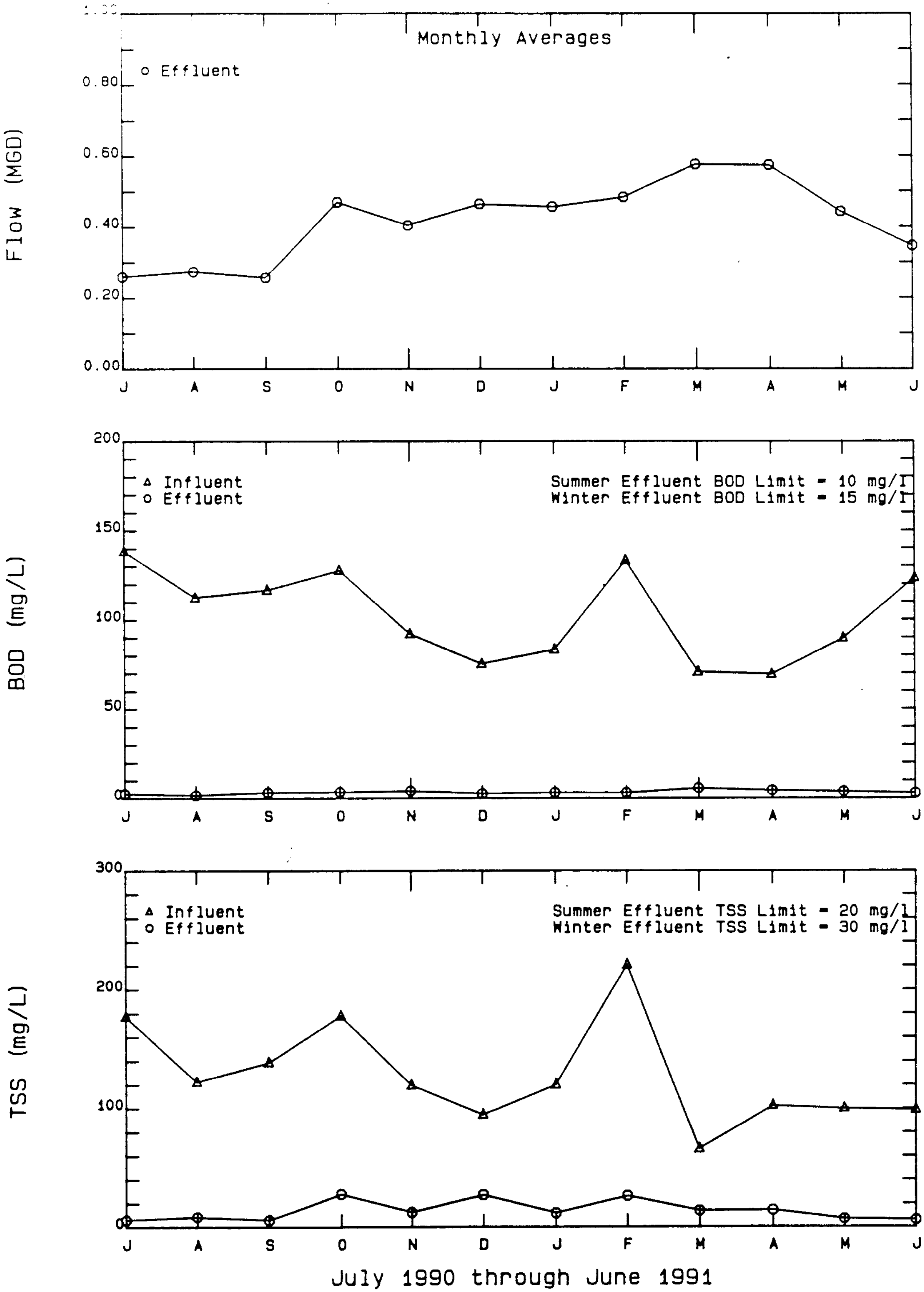
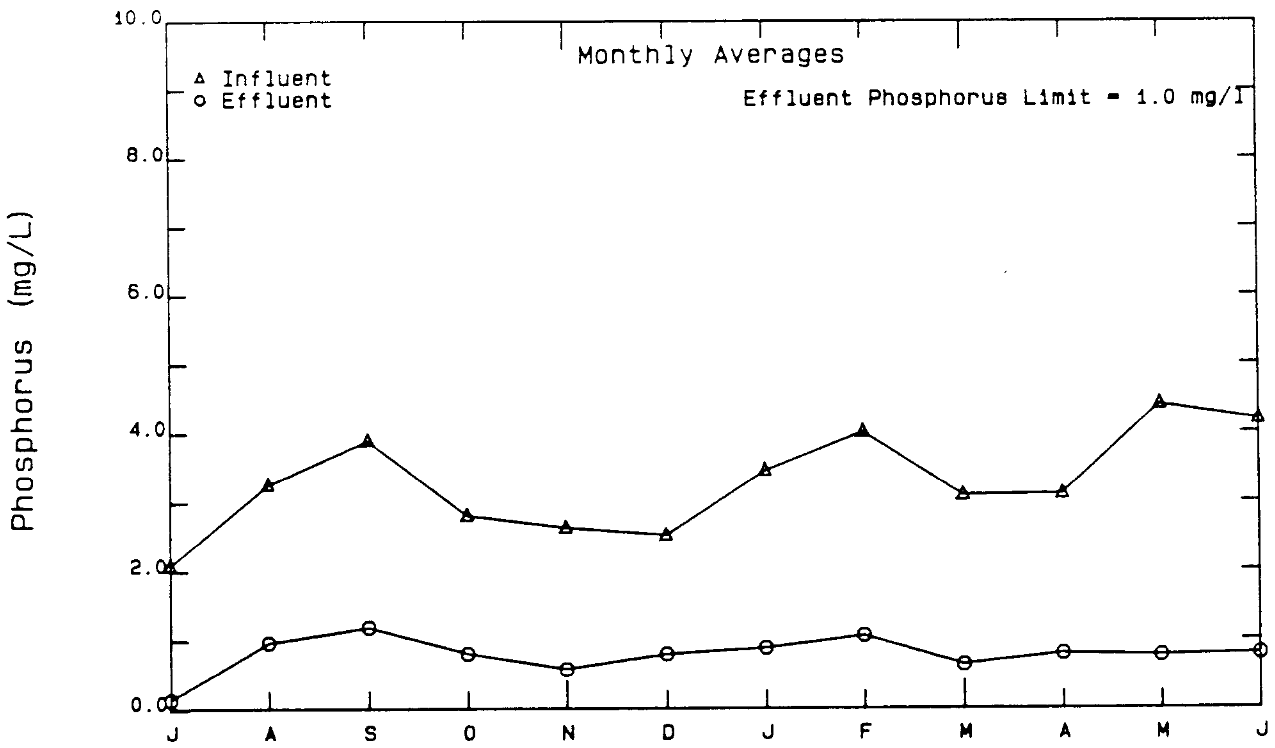


Figure 4. Chronological Plots of Monthly Average Data
Marlette, Michigan



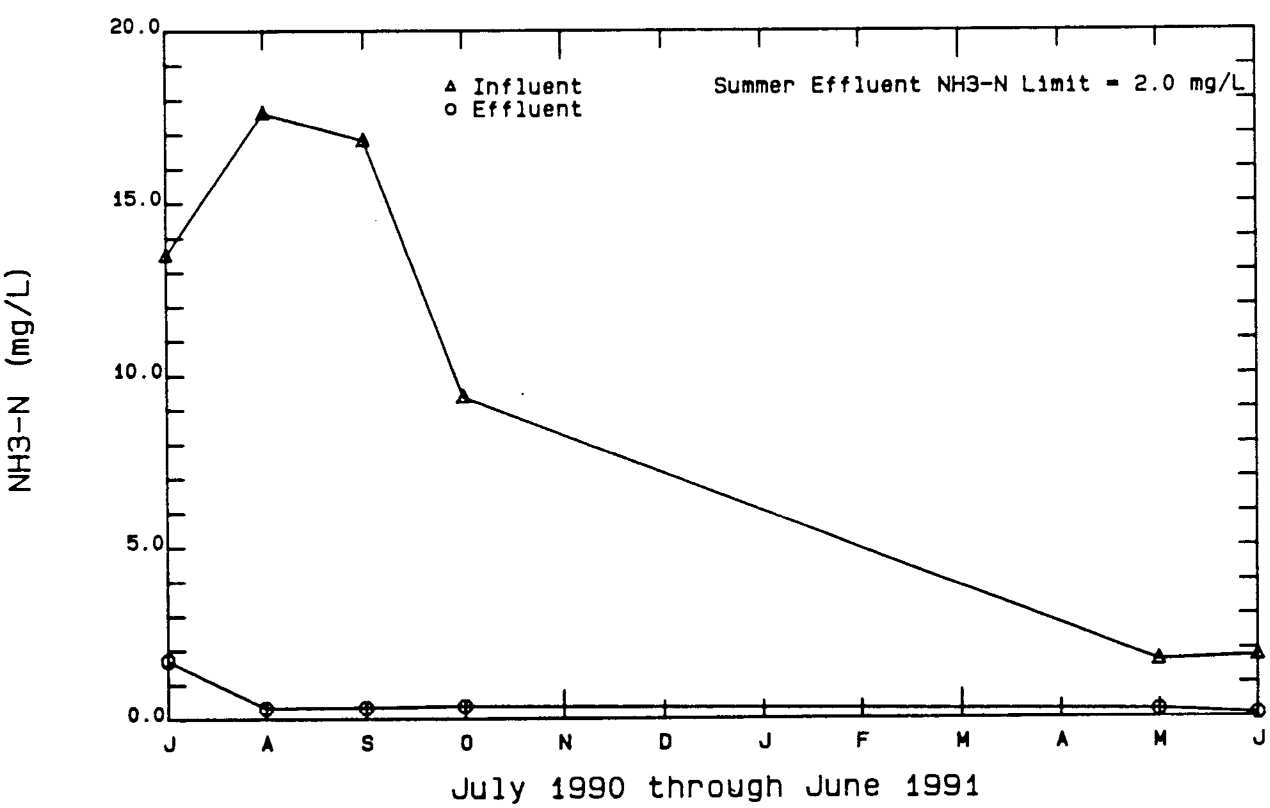


Figure 5. Chronological Plots of Monthly Average Data
Marlette, Michigan

possible explanation for the decrease in influent NH_3-N may be process changes implemented in a fertilizer plant that discharges to the treatment plant. This, however, was not confirmed. Nitrification was occurring as indicated by the oxidation of NH_3-N that averaged 95 percent. The plant consistently met the permitted NH_3-N limit.

The average influent total phosphorus during the period July 1990 through June 1991 was 3.3 mg/l. Approximately 76 percent of the phosphorus in the influent was removed during treatment. The monthly average effluent phosphorus concentration was below the permit limit of 1.0 mg/l for 10 of the 12 months with available data.

The plant is staffed by two full time operators. It is estimated that approximately 2.5 hours a day are spent on process control of the SBR. This includes controlling sludge wasting and performing laboratory analyses. The plant superintendent and operator were both generally satisfied with the SBR and its operation. There was originally a problem with air in the decanter, however, it was resolved, and there have been no other major problems.

Grafton, Ohio

The current Grafton, Ohio treatment plant is an SBR upgrade of a trickling filter plant. The SBRs went on line in December 1988. The plant was designed for an average daily flow of 0.75 MGD. The plant influent passes through a grit chamber prior to the SBRs. Only two of the plant's three SBRs are currently in use. The SBRs are equipped with jet aerators. The SBR effluent flows to a chlorine contact chamber prior to discharge.

The plant receives flow from two local prisons, a small chrome plater, a plastic extrusion factory, a foundry, and a circuit board manufacturer in addition to domestic waste. The wastewater flow from the plastic extrusion factory and the circuit board manufacturer is pretreated prior to entering the plant. The plant attributes the high levels of zinc in the sludge to a zinc plater that previously discharged to the plant. The sludge is stored in the third SBR prior to disposal. Plant effluent requirements are shown in the following table.

Grafton, Ohio Plant
Monthly Average Effluent Limits - mg/l

Period	$CBOD_5$	TSS	NH_3-N	P[a]
Summer	10	20	1.5	No Limit
Winter	25	30	15	No Limit

[a]Monitoring of phosphorus and NO_3-N required

The three SBRs are manufactured by Fluidyne, and have a volume of approximately 0.43 million gallons each. The SBRs were designed for nitrification, denitrification, and phosphorus removal. The capability for chemical addition for phosphorus removal exists, but has never been used. The SBR was designed for a 41 hour hydraulic detention time at average design flow, MLSS ranging from 2000 to 2500 mg/l, and an SRT of 20 days. It was being operated at a MLSS between 3000 and 4000 mg/l at the time of the site visit.

Grafton uses an air on/off sequence to achieve biological nutrient removal. The blowers cycle during both REACT and IDLE. The aeration period is adjusted by the operator and is changed seasonally, or as conditions require. The FILL period varies with influent flow. Presently, SETTLE is 70 minutes and DECANT is 50 minutes.

Chronological plots summarizing the monthly average flow, CBOD, NH_3-N, NO_3-N, and total phosphorus for January 1989 through March 1991 are presented in Figures 6 and 7. During this period the plant operated at an average influent flow of 0.53 MGD or approximately 71 percent of design. The only plant influent data available were CBOD. Effluent CBOD, NH_3-N, NO_3+NO_2-N and total phosphorus data were available. Approximately 97 percent of the BOD entering th^ plant was removed. Effluent ammonia nitrogen is measured year round. The average summer effluent NH_3-N concentration during the period was 0.94 mg/l. The monthly average effluent NH_3-N concentration was below the permit limit in 8 of the 11 summer months with data. The plant met its winter NH_3-N limits in all 12 of the winter months. Effluent NO_3^-+NO_2-N were measured once per month from September 1989 to March 1991. The effluent total phosphorus concentration averaged 1.4 mg/l from January 1989 to March 1991.

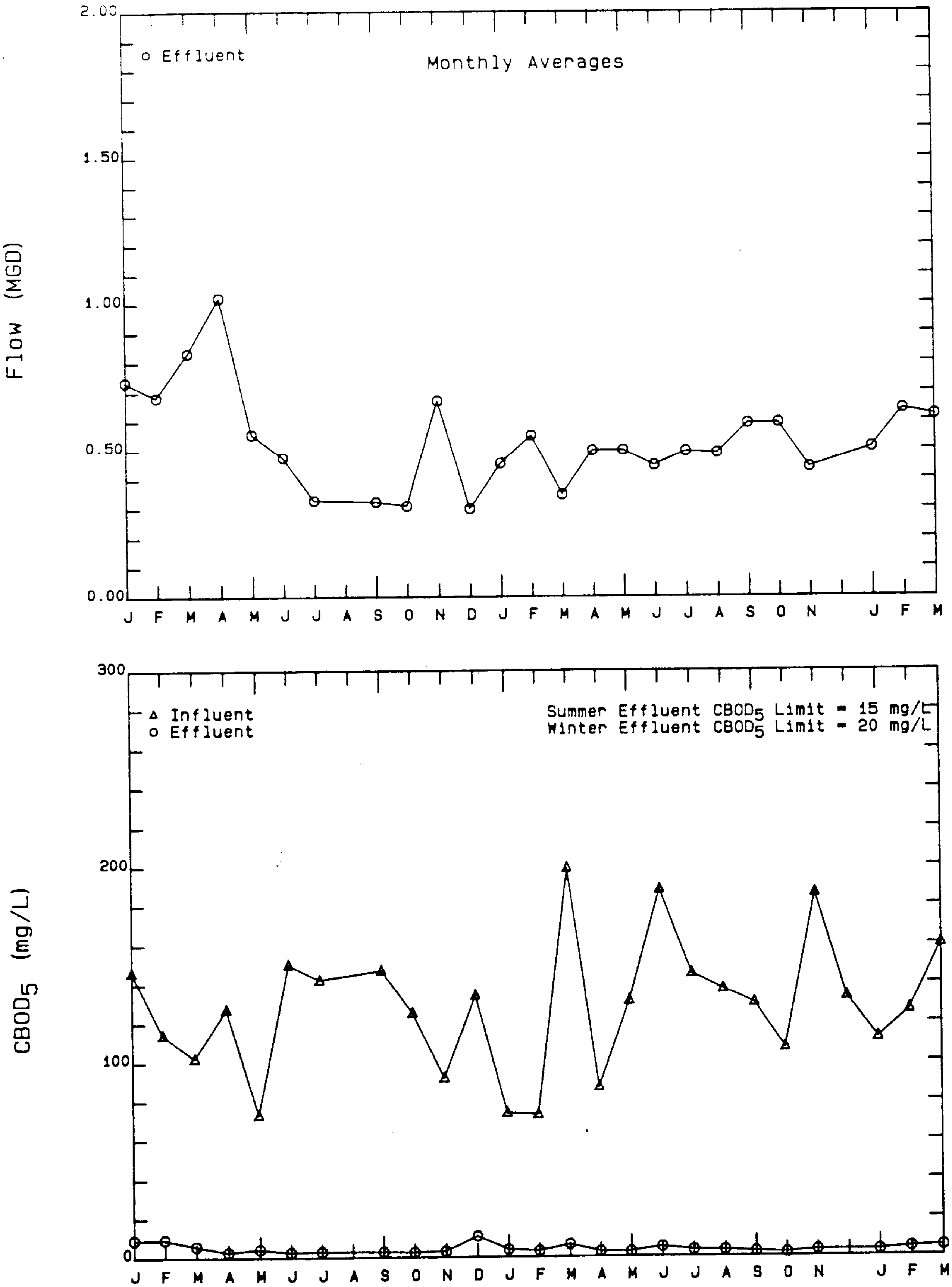


Figure 6. Chronological Plots of Monthly Average Data
Grafton, Ohio

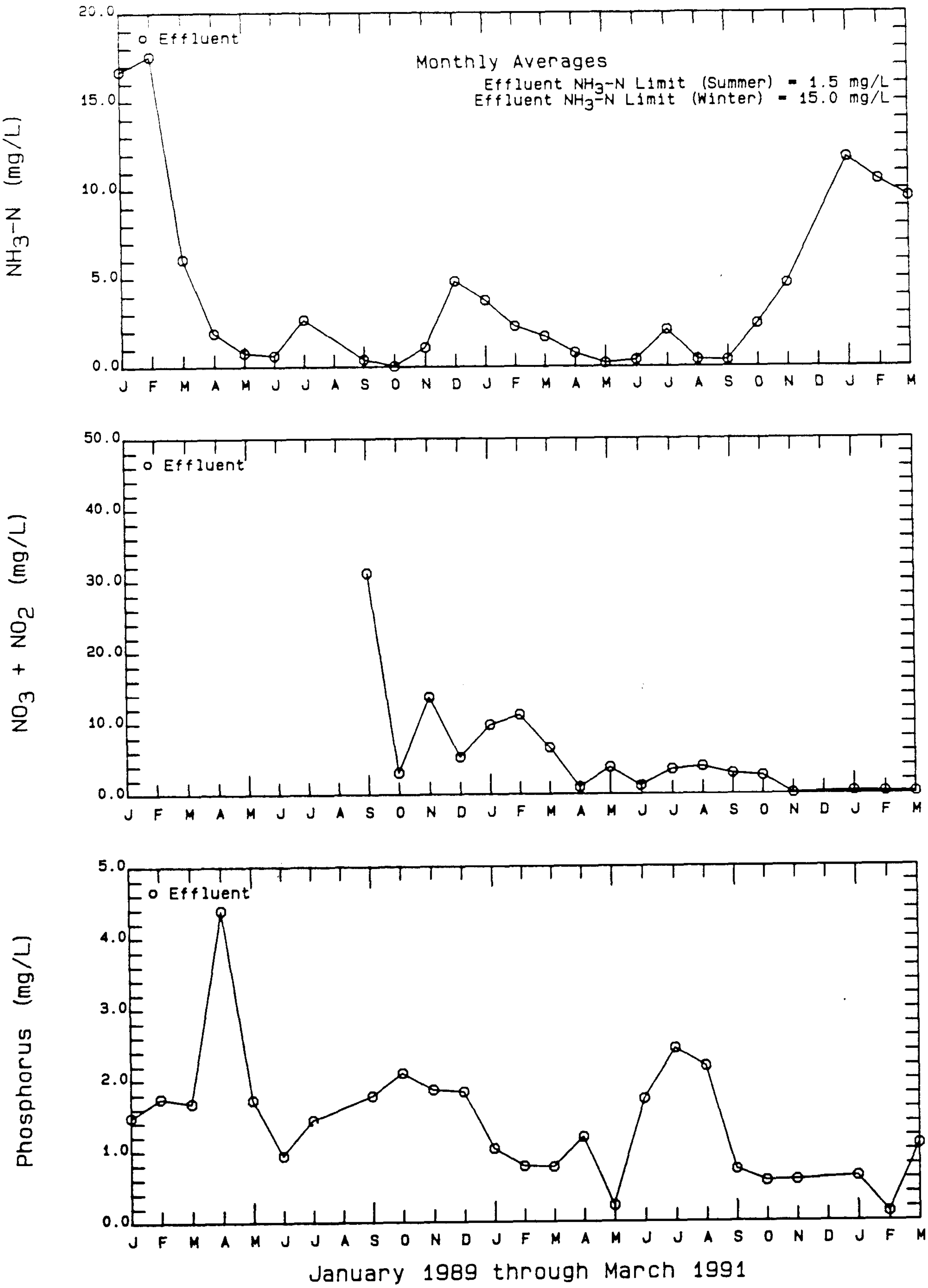


Figure 7. Chronological Plots of Monthly Average Data
Grafton, Ohio

The plant is staffed by one full time operator. All analytical work is sent to an outside laboratory. The operator estimates he spends approximately one hour a day on routine maintenance of the SBR. The plant operator was generally satisfied with the SBR and its operation. There have been no serious problems with the SBR.

Shelter Island Heights, New York

The wastewater treatment plant on Shelter Island, began operation in June 1988. It was designed for an average daily dry weather flow of 0.028 MGD, a peak dry weather flow of 0.072 MGD and a peak wet weather flow of 0.15 MGD. Shelter Island, located in the eastern part of Long Island, is a summer resort and has much higher flows during the summer than in the winter. Peak dry weather flows during August have in the past reached 0.12 MGD.

The plant has two Austgen Biojet SBRs. There are no grit chambers, bar screens, or comminutor before the SBRs. Grit, however, collects in the splitter box that divides the flow between the two reactors. The SBR effluent is chlorinated before discharge to Long Island Sound. The SBR was designed for nitrification and denitrification but not for phosphorus removal.

The plant was designed to treat a BOD load of 44 lbs/day and a TSS load of 57 lbs/day at the average daily dry weather flow. The plant was designed for a NH_3-N loading of 8.7 lbs/day and a TKN loading of 11 lbs/day. The plant's effluent permit limits are a 30 day average BOD of 30 mg/l and TSS of 30 mg/l. The plant is required to meet a 30 day total nitrogen limit of 10 mg/l year-round. The plant has no effluent phosphorus limit.

The SBRs were designed for a normal cycle time of 6 hours with an anoxic mix and a normal cycle time of 4 hours without an anoxic mix. The plant is typically operated with a five or six hour cycle time for denitrification from October to mid May and with a four hour cycle time from mid May through September. The operator reported that cycle times are changed about four times per year, depending on flow. A typical 4 hour cycle time includes a two hour react cycle, a one hour settle cycle, and a one hour draw cycle.

Chronological plots summarizing the monthly flow, BOD, TSS, TKN, NO_3-N, and total nitrogen data for January 1989 through July 1991 are presented in Figures 8 and 9. Samples are typically collected once per month. During the period evaluated, the plant operated at an average summer flow (May through October) of 0.037 MGD or 137 percent of design average dry weather flow (51 percent of the design peak dry weather flow). During the winter months (November through April) the flow averaged 0.015 MGD or 53 percent of the design average dry weather flow. The percent BOD removal averaged 96 percent in both the summer and winter. The TKN data shows that nitrification was occurring. The BOD consistently met the permit limit of 30 mg/l. The effluent total nitrogen averaged approximately 8 mg/l in both the summer and winter. The plant met the total nitrogen permit limit of 10 mg/l in 21 of the 29 months. The average percent total nitrogen removal was 56 percent.

The plant is staffed by one operator. It is estimated that between two and three hours per day of the operator's time is spent operating the SBR. The operator was satisfied with the SBR and its operation. The plant is situated adjacent to the local beach and private beachhouse and has never received any complaints about odors. There have been no major problems with the SBR.

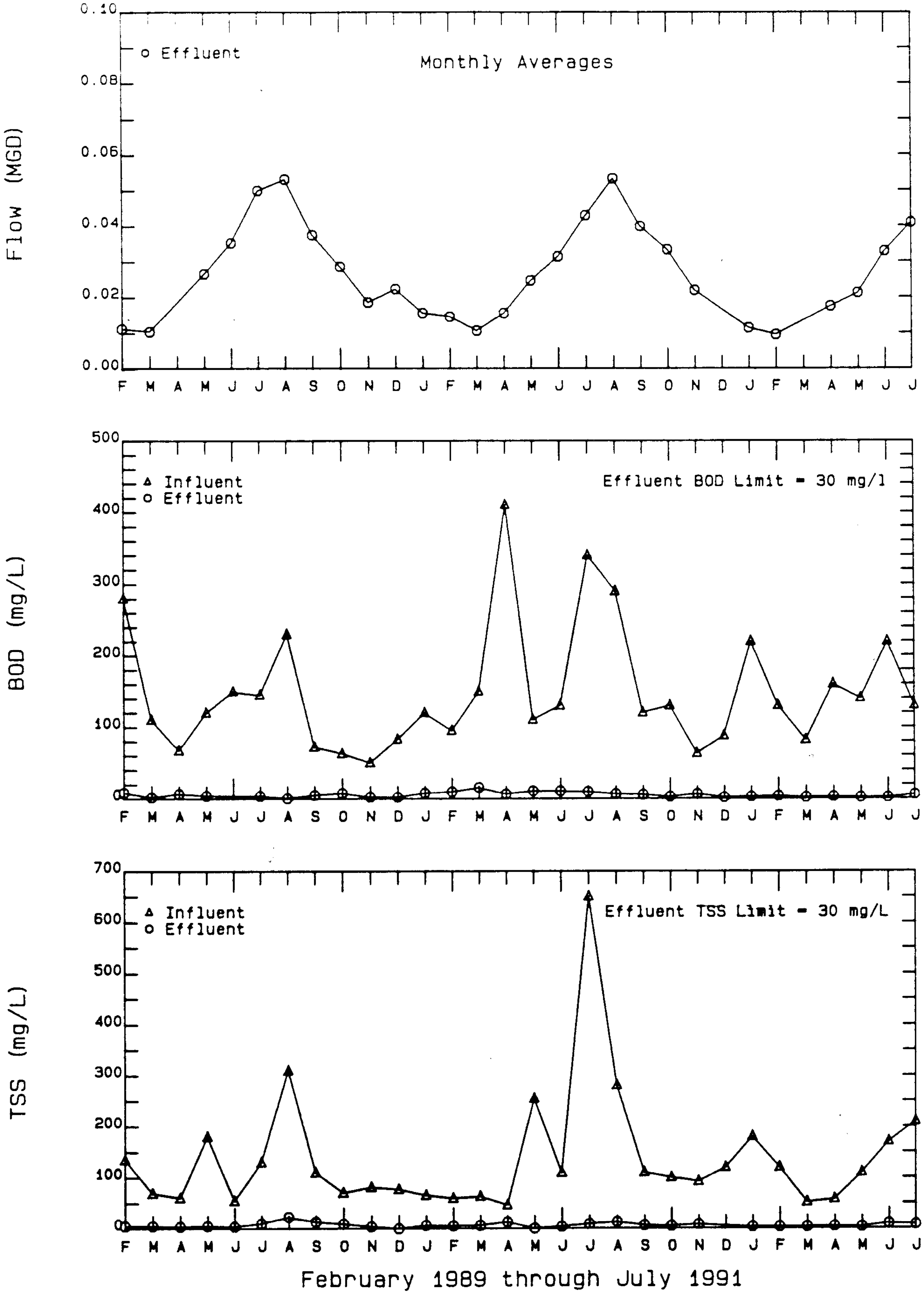


Figure 8. Chronological Plots of Monthly Average Data
Shelter Island, New York

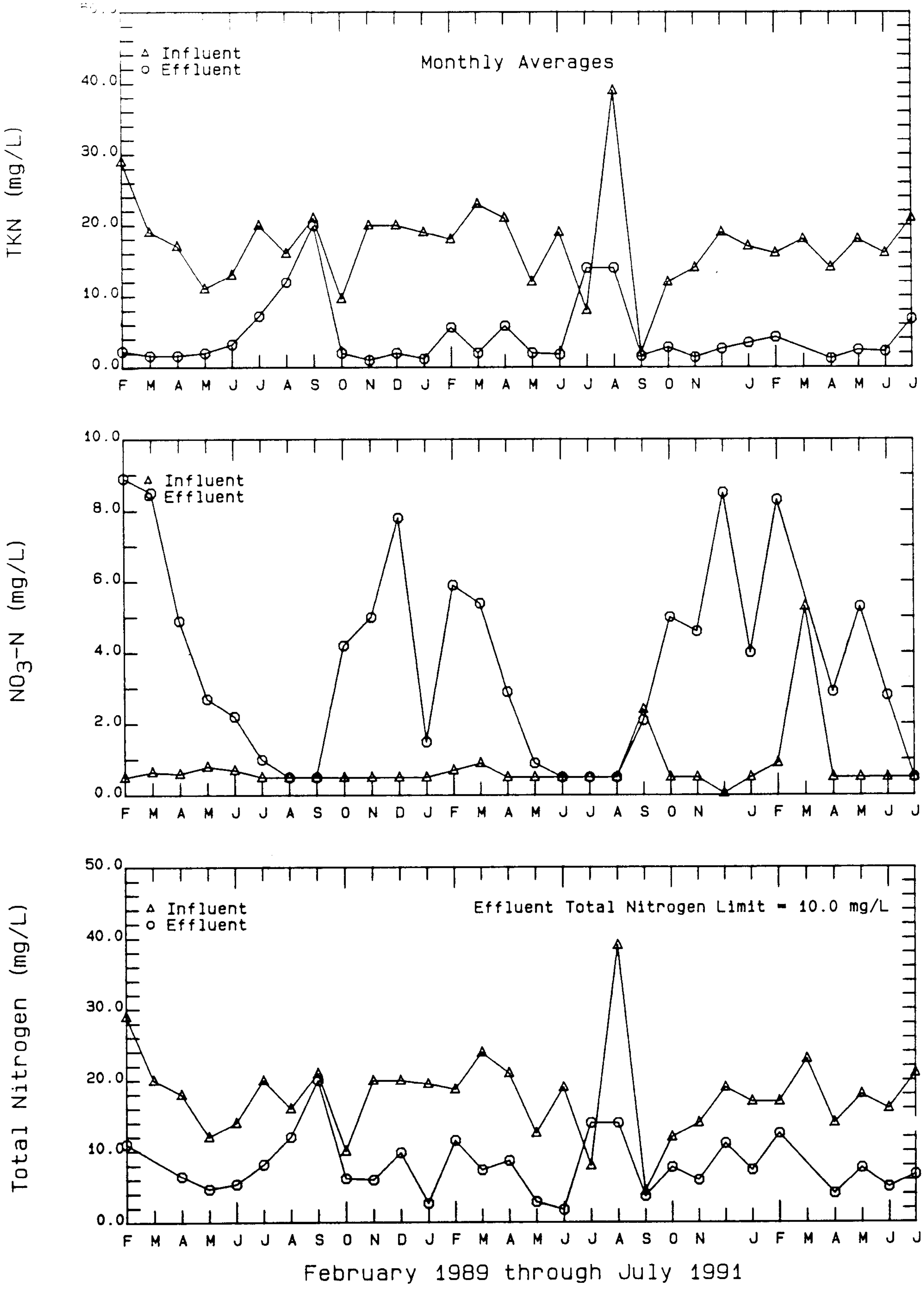


Figure 9. Chronological Plots of Monthly Average Data
Shelter Island, New York

SECTION 5.

ANALYSIS OF SBR PLANT PERFORMANCE DATA

PERMIT LIMITS

Effluent permit limitations for the nineteen treatment plants included in the performance evaluation are shown in Table 4. Also listed in Table 4 are the manufacturêr of each plant and its design flow. Twelve of the 19 plants have effluent ammonia limits, while three are required to monitor for ammonia. The effluent limits ranged from 1.5 to 10.0 mg/l during the summer months. Two plants have nitrate plus nitrite limits and two have total inorganic nitrogen limits. Effluent limits on total nitrogen are required for two plants. Five plants have effluent phosphorus limits that ranged from 0.5 to 2.0 mg/l.

PLANT DATA

The performance data for 19 plants are summarized in Table 5. The available monthly average data for each plant are presented in Appendix A. BOD and TSS removal ranged from 84.7 to 97.4 percent and consistently met effluent requirements. These removal rates are similar to those achieved by conventional activated sludge systems.

The 19 plants evaluated in the study were all originally designed for nitrification and are believed to be presently operating under conditions favoring nitrification. Influent and effluent ammonia nitrogen data were available for 8 plants. Removal ranged from 90.8 to 96.8 percent. The average effluent ammonia nitrogen concentration for each of the 8 plants was less than 2.0 mg/l. The low effluent concentrations indicate that nitrification was occurring.

TABLE 4. SUMMARY OF EFFLUENT PERMIT LIMITATIONS FOR 19 SBR PLANTS

Plant Location	SBR Manufacturer	Design Flow (mgd)	Effluent Limits (mg/l)					
			BOD/CBOD	TSS	NH_3-N	NO_3-N $+NO_2$-N	Total N	Total P
Armada, MI	JetTech	0.3	15^S	30^S	4^S			1^S
Buckingham, PA	Austgen Biojet	0.236	$10^S/20^W$	30^{SW}	$3^S/9^W$	8^S		[illegible]^S
Caledonia, MN	Fluidyne	0.52					10	
Clarkston, MI (Chateau Estates)	Aqua-Aerobics	0.11	30	30	5.0 TIN			
Conover, NC (Southwest WWTP)	Austgen Biojet	0.3	30	30	DM		QM	QM
Del City, OK	JetTech	3.0	20	30	WM			
Dundee, MI	Transenviro	0.75	$9^S/25^W$	$26^S/30^W$	3^S			0.5^{SW}
Fairchance, PA	Austgen Biojet	0.35	15	25	$1.5^S/5.0^W$			
Grafton, OH	Fluidyne	0.75	$15^S/20^W$	$20^S/30^W$	$1.5^S/15^W$			
Grundy Center, IA	Aqua-Aerobics	0.8	25	30	8.5			
Manchester, MI	JetTech	0.52			10			1
Marlette, MI	JetTech	0.69	$10^S/15^W$	$20^S/30^W$	2^S			1
McPherson, KS	JetTech	2.0	$20^S/30^W$	30^{SW}	$3^S/12^W$			
Mifflinburg, PA	Aqua-Aerobics	0.9	$20^S/25^W$	30	$3.0^S/9.0^W$			
Monticello, IN (White Oaks Resort)	Austgen Biojet	0.05	10^{SW}	12^{SW}	$1.5^S/3.0^W$			1^{SW}
Muskegon Heights, MI (Clover Estates)	Aqua-Aerobics	0.045	30	30	5.0 TIN			
Shelter Island. NY	Austgen Biojet	0.028	30	30			10	
Walnut Grove, PA	Transenviro	0.025	30	30		5		
Windgap, PA	Aqua-Aerobics	1.0	$10^S/20^W$	30	$2.0^S/6.0^W$			

^{S}Summer
^{W}Winter
TIN Total Inorganic Nitrogen
DM Daily monitoring
QM Quarterly monitoring
WM Weekly monitoring

Effluent ammonia data concentrations for six plants ranged from 0.17 to 1.74 mg/l. These low concentrations indicate that nitrification was most likely occurring, at least during the summer months. Manchester, Michigan supplied monthly maximum effluent ammonia data, however, without influent data for a comparison, the maximum effluent concentration of 6.6 mg/l ammonia nitrogen was too high to indicate if any nitrification was occurring. The twelve plants with effluent ammonia limits were consistently able to meet their requirements, including Manchester, Michigan (average limit 10 mg/l).

Limited information was available to evaluate denitrification in SBRs. Few of the plants surveyed have effluent limitations on nitrate or total nitrogen and therefore do not measure for these constituents. Two of the 19 plants evaluated measured effluent total nitrogen, and 6 plants measured effluent nitrate and nitrite nitrogen. Shelter Island measured both nitrate and nitrite nitrogen and TKN in order to report total nitrogen concentrations. Buckingham, which measured effluent nitrate and nitrite nitrogen, also supplied limited summer TKN data. Effluent nitrate and nitrite nitrogen data ranged from 2.11 to 5.6 mg/l for the 6 plants.

Under denitrifying conditions, nitrate would be converted to nitrogen gas and removed from the wastewater. Significantly low effluent ammonia and nitrate nitrogen concentrations (much less than the influent ammonia nitrogen concentration) would indicate that both nitrification and denitrification were occurring. Data from Buckingham, Clarkson, and Muskegon Heights indicate that denitrification occurred at these plants. Relatively low effluent concentrations of nitrate + nitrite nitrogen and total nitrogen at Caledonia, Conover, Grafton, and Walnut Grove indicate that denitrification was probably occurring, to some degree, at these plants. Three plants, Armada, Dundee, and McPherson, were designed for denitrification. Information on nitrate or total nitrogen, however, was not available and denitrification could not be verified.

TABLE 5. SUMMARY OF PERFORMANCE DATA FOR 19 SBR PLANTS

Plant Location	Period of Analysis	Flow (mgd)	% of Design Flow	BOD/CBOD (mg/l)			TSS (mg/l)			NH_3-N (mg/l)			TKN (mg/l)			NO_3-N+NO_2-N (mg/l)		Total P (mg/l)		
				INF	EFF	% REM	INF	EFF	% REM	INF	EFF	% REM	INF	EFF	% REM	INF	EFF	INF	EFF	% REM
Armada, MI	1/89-3/91	0.293	98				-	11.4	-										[illegible]	
Buckingham, PA	4/89-4/91	0.116	49	324	8.4	97.4	208	7.2	96.5	25.3	1.07	95.8	67.8	11.6S	82.9		2.11	[illegible]	[illegible]	
Caledonia, MN	4/88-4/91	0.294	57	229	7.6	96.7	267	15.3	94.7								TN - 1[illegible]			
Clarkston, MI (Chateau Estates)	11/89-4/91	0.055	50	192	12.4	93.5	260	7.4	97.2	39.1	1.68	95.7					3.11			
Conover, NC (Southeast Plant)	1/89-6/91	0.26	87	256	8.0	96.7	183	9.6	94.8	-	0.92	-				-	TN - 6.2[1]		[illegible]	
Del City, OK	1/90-6/91	2.6	87	158	5.0	96.8	136	7.0	94.9		0.45	-								
Dundee, MI	10/89-3/91	0.7	93	108	3.2	97.0	56	3.7	93.4	-	1.74	-							[illegible]	
Fairchance, PA	1/90-6/91	0.195	56	-	12.0	-	-	12.5		-	0.45	-								
Grafton, OH	12/88-3/91	0.5	67	130	4.2	96.8				-	0.94S 4.92W[3]	- -				-	5.6		1.40	
Grundy Center, IA	12/89-11/90	0.575	72	195	3.8	98.1	169	7.6	95.5	15.8	1.24	92.2								
Manchester, MI	10/89-3/91	0.39	75	-	3.0	-	-	52.0	-		6.6[2]	-							1.12	
Marlette, MI	7/90-6/91	0.417	60	103	3.5	96.6				10.1	0.51	95.0						3.3	0.78	CH
McPherson, KS	6/90-6/91	1.8	90	218	6.2	97.2	188	10.6	94.4		0.17	-								
Mifflinburg, PA	10/88-3/91	0.73	81	105	11.7	88.9	-	9.8	-	7.8	0.42	94.6								
Monticello, IN (White Oaks Resort)	10/89-5/91	0.004	8	131	4.8	96.3	77	4.8	93.8	3.1	0.285	90.8						2.6	0.45	CH
Muskegon Heights, MI (Clover Estates)	1/88-10/90	0.035	78	185	9.1	95.1	132	20.2	84.7	21.2	0.67	96.8				-	3.55	4.3	1.85	57
Shelter Island, NY	1/89-7/91	0.026	93	148	5.6	96.2	135	6.5	95.2				17.5	4.4	74.9	0.8	3.69			
Walnut Grove, PA	5/90-4/91	0.006	24	-	14.0	-	-	16.1	-							-	2.75			
Windgap, PA	2/90-10/90	0.559	56	160	6.6	95.6	131	5.2	96.0	12.9	0.59	95.4								

[1]1989-90 quarterly data
[2]Monthly maxima
[3]Some start-up data omitted

[S]Summer average
[W]Winter average
[CH]Chemical added
[TN]Total Nitrogen

Phosphorus removal has become an important concern in many areas, most notably in States surrounding the Great Lakes and Chesapeake Bay. Six of the 19 plants evaluated have effluent phosphorus limitations; four of these are located in Michigan. In addition, Conover, North Carolina is required to monitor quarterly for phosphorus.

Influent phosphorus data was very limited. Four plants that measured influent phosphorus concentrations had concentrations from 2.6 to 12.0 mg/l. Nine of the plants measured effluent phosphorus levels. Two of these plants, Marlette and Monticello, add ferric or ferrous chloride for phosphorus removal, though Marlette only adds the chemical during storm events. Effluent phosphorus concentrations for the eight plants, not including Monticello, ranged from 0.53 to 4.27 mg/l. The seven plants that did not add ferric or ferrous chloride, and Marlette during normal flows, rely solely on biological phosphorus removal. The relatively low concentration of phosphorus in the effluent indicate that at least some phosphorus is being removed biologically, beyond that normally expected from sludge wasting. Armada, Dundee, Manchester, and Marlette usually met their effluent phosphorus requirements, with an occasional excursion beyond limits. Buckingham's limit of 2.0 mg/l in the summer was rarely met, although the plant averaged 64 percent removal of influent phosphorus. Buckingham has the option of discharging to a holding lagoon for subsequent spray irrigation and is only required to meet effluent limits when discharging to a stream.

The following is a short discussion on each plant that provided data on performance. The three plants that were visited and discussed in Section 5 are not included. Additional information on the design and operating conditions, and problems of the plants are discussed.

Armada, Michigan

This plant consists of three SBR tanks manufactured by JetTech. Screening and grit removal precede the SBRs. This system is equipped with fine bubble diffusers. Three full-time operators handle the 0.3 MGD facility, as well as performing laboratory analyses. The plant usually operated with a srt of 20 to 30 days, but occasionally reached 90 days with good results. The F/M ratio typically ranged from 0.02 to 0.04 lb BOD/lb MLSS/day. The total cycle time was normally 7 hours, and included 20 minutes aerated fill, 120 minutes anoxic fill, 120 minutes aeration, 60 minutes settle, 30 minutes decant, and 70 minutes idle. The plant began operating in July 1988.

Buckingham, Pennsylvania

This Austgen Biojet plant operated with two ICEAS(R) SBRs equipped with coarse bubble diffusers. This 0.1 MGD plant is run by two full-time operators. The influent is screened before it enters the SBRs. The plant was designed to operate at a F/M ratio of 0.045, and had a cycle time of four hours. The cycle consisted of 2 hours aeration, 57 minutes sedimentation, and 56 minutes decant. As with all ICEAS(R) systems, the tanks fill continuously.

Caledonia, Minnesota

This plant, manufactured by Fluidyne, was constructed with three SBRs but was operating only two. The SBRs are equipped with jet aerators, and are preceded by a grit chamber and primary clarifier. Twenty to 30 percent of the wastewater flows through a trickling filter before it enters the SBRs. This acts to lower the BOD loading and enhances subsequent nitrification in the SBR. Two operators handle the operation of the SBR along with other Water Department duties. This plant has had some operational problems and has worked with Transenviro to solve them. Waste from a milk transfer station contributes to loading problems. To improve performance, the plant is trying to raise MLSS concentration to 3500 mg/l. Total cycle time was five to six hours, and included 30 minutes anoxic fill, and 120 minutes aeration. Plant start-up was in November 1987.

Clarkston, Michigan - Chateau Estates Mobile Home Park

This plant was manufactured by Aqua-Aerobic Systems and consists of one SBR preceded by an equalization tank. It has been equipped with floating mixers in addition to coarse bubble diffusers. The MLSS concentration ranged from 1850 to 4500 mg/l and averaged 3200 mg/l. The F/M concentration varied from 0.023 to 0.082 and averaged 0.04 lb BOD/lb MLSS/day. The total cycle time was 5 hours and 50 minutes. Plant start-up was in October 1989.

Conover, North Carolina - Southeast Plant

This Austgen Biojet plant consists of two ICEAS^R SBRs equipped with jet aerators. It was constructed in 1985 and has an average flow of 0.26 MGD. The total cycle time was 3 hours, which included 90 minutes aeration, 35 minutes settle, and 55 minutes decant.

Del City, Oklahoma

This plant, with an average flow of 2.6 MGD, was manufactured by JetTech and consists of two SBRs equipped with jet aerators. The SBRs are preceded by a comminutor and grit removal system. The total cycle time is varied between 4 and 6 hours, depending on the flow. Effluent from the SBRs passes through an ultraviolet disinfection (UV) unit.

Dundee, Michigan

This Transenviro plant consists of two SBRs equipped with medium bubble diffusers. The SBRs are preceded by a comminutor, bar screen, and grit chamber. Three full-time operators are employed by the facility. The flow averaged 0.7 MGD. The plant operated at a MLSS between 2500 and 3000 mg/l. The SRT is checked daily and averaged 17 to 20 days. Total cycle time was 4 hours, with 2 hours aeration, 50 minutes settle, and 70 minutes decant. Plant startup was in September 1989.

Fairchance, Pennsylvania

This Austgen Biojet plant consists of four ICEAS(R) SBRs preceded by a bar screen. The Fairchance-Georges WWTP has an average flow of 0.2 MGD and is staffed by one full-time operator and one relief operator. Normal cycle time was 4 hours and included 120 minutes aeration, 60 minutes settle and 60 minutes decant. Plant start-up was in April 1989.

Grundy Center, Iowa

This plant, manufactured by Aqua-Aerobic Systems, consists of two SBRs equipped with fine bubble diffusers and a separate mixer. The MLSS concentration in the two SBRs ranged from 1800 to 2800 mg/l and averaged 2300 mg/l. The F/M ratio averaged 0.09 lb BOD/lb MLSS/day. Total cycle time was 288 minutes (4.8 hours) and included 15 minutes fill, 84 minutes react, 45 minutes settle, and 40 minutes decant. Plant start-up was in April 1988.

Manchester, Michigan

This plant was manufactured by JetTech with three SBRs, but only two are typically used. The third is used during periods of high infiltration. The MLSS concentration is normally about 3500 mg/l but has been operated as high as 8000 mg/l. Total cycle time is 7.5 hours and includes 3.75 hours fill, 95 minutes aeration, and 45 minutes settle.

McPherson, Kansas

This plant, manufactured by JetTech, utilized three SBRs equipped with jet aerators. The SBRs are preceded by a bar screen and grit removal system. Total cycle time is normally 6 hours and includes 1 to 2 hours aeration, 18 minutes settle, 45 minutes decant, and 90 minutes idle. Plant start-up was in June 1990.

Mifflinburg, Pennsylvania

This Aqua-Aerobic Systems plant consists of two SBRs equipped with fine bubble diffusers and separate mixers. The MLSS concentration in the two SBRs averaged 2500 mg/l. The F/M ratio averaged 0.028 lb BOD/lb MLSS/day. Total cycle time was 6.5 hours and included 36 minutes mixed fill, 97 minutes react, 75 minutes settle, and 45 minutes decant. React includes mixing with alternating periods of aeration and no air. Plant start-up was in August 1988.

Monticello, Indiana - White Oaks on the Lake Resort

This Austgen Biojet plant consists of two ICEAS(R) SBRs designed for 0.05 MGD. Current flow averages 0.004 MGD. One part-time operator devotes 10 to 15 hours per week to the operation and maintenance of the system. Ferrous chloride is added to assist in phosphorus removal. Total cycle time is four hours during the summer and six hours in the winter.

Muskegan Heights, Michigan - Clover Estates Mobile Home Park

This Aqua-Aerobic Systems plant consists of one SBR equipped with coarse bubble diffusers and a separate mixer. Flow averaged 0.035 MGD. The mixed liquor concentration averages 3400 mg/l. Plant start-up was October 1987.

Walnut Grove, Pennsylvania

This is a Transenviro plant with one SBR equipped with coarse bubble diffusers. Present flow, which comes entirely from an apartment complex, averages 0.006 MGD. Effluent is discharged into a sand mound. The plant has a subterranean discharge permit. Total cycle time was 4 hours and included 75 minutes aeration, 75 minutes settle, and 90 minutes decant, skim and idle. The SBR fills during aeration and idle. Plant startup was in April 1990.

Windgap, Pennsylvania

This Aqua-Aerobic Systems plant consists of two SBRs equipped with coarse bubble diffusers. Plant startup was in August 1989.

SECTION 6.

COST ANALYSIS

INTRODUCTION

Capital and operating costs were obtained from plant operators and plant design engineers. Table 6 presents the utility, operating, and capital or construction cost information that was available for this analysis. The capital costs were adjusted to 1991 dollars using the Engineering News Record (ENR) Construction Cost Index. Figure 10 presents the available utility, operating and capital costs.

Greenfield, Tullahoma, and Cow Creek supplied cost data but did not include plant operating data. The Conover, North Carolina Northeast plant is still under construction and the information supplied is the bid price.

CAPITAL COSTS

Construction costs were available for six plants, and five plants supplied total capital costs. Construction costs were converted to capital costs by adding 15 percent for engineering and construction supervision, and 15 percent for contingencies. All capital costs were adjusted to July 1991 costs. The costs ranged from $1.93 to $30.69/gpd of design flow.

Shelter Island, with a cost of $30.69/gpd, was said to have cost two to three times over budget, due to construction problems. In addition, Shelter Island had certain aesthetic requirements due to its proximity to a private beach and clubhouse.

The wide range in capital costs was influenced by whether the SBR was retrofitted into existing plant structures or newly constructed, influent concentrations, effluent limitations, or additional design requirements.

TABLE 6. COST DATA FOR SEQUENCING BATCH REACTORS WASTEWATER TREATMENT FACILITIES

Facility	Design Flow, mgd	Actual Flow, mgd	Startup Date	Utility Costs $/year	Operating Costs $/year[a]	Actual Construction Costs $	Actual or Estimated Capital Costs $[b]	Adjusted Capital Costs 1991 $	Utility Cost per 1990 Flow $/gpd	Operating Cost per 1990 Flow $/gpd	Capital Cost per Design Flow $/gpd
Armada, MI	0.3[illegible]0	0.293	1988			3,500,000	4,550,000	4,887,187			[illegible]
Buckingham, PA	0.236	0.133	1989	37,777	234,058	2,314,050	3,008,265[a]	3,163,984	0.28	[illegible]	[illegible]
Caledonia, MN	0.520	0.294	1987			1,400,000	1,820,000	2,005,011			[illegible]
Conover, NC (Northeast Plant)	1.500		1991			3,712,840	4,826,692	4,826,692			[illegible]
Conover, NC 6 (Southeast Plant)	0.300	0.260	1985			908,540	1,181,102	1,366,612			[illegible]
Cow Creek, OK	6.000	2.500		182,500					0.07		
Dundee, MI	0.750	0.700	1989			3,400,000	4,420,000	4,648,796			6.20
Greenfield, PA	0.140	0.040	1988				1,290,000	1,385,598			9.90
Marlette, MI	0.690	0.417	1990				3,000,000	3,077,276			4.46
McPherson, KS	2.000	1.57	1990	90,000	269,500				0.06	0.17	
Monticello, IN (White Oaks Resort)	0.050	0.005	1989		14,400	280,000	294,494			2.88	5.89
Shelter Island, NY	0.028	0.022	1988	12,000			800,000	859,286	0.55		30.69
Tullahoma, TN	3.000	2.500	1985			5,000,000	5,765,328				1.93

[a]Operating costs include labor, utilities, maintenance, chemicals, supplies, etc.
[b]When an actual construction cost is given, capital cost was estimated from construction cost by adding 15% for engineering and construction supervision and 15% for contingencies

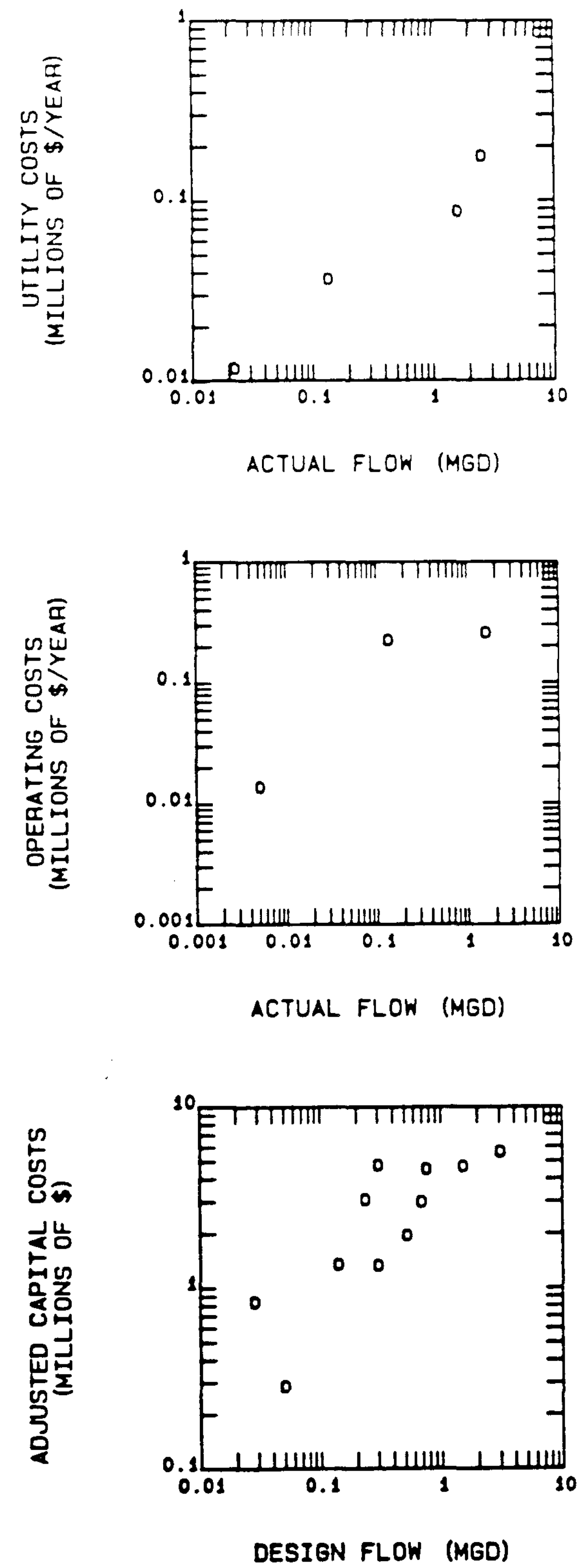


Figure 10. Utility, Operating and Capital Costs
Supplied by SBR Facilities

OPERATION AND MAINTENANCE COSTS

Overall 1990 operating costs were available for 3 plants. Operating costs based on 1990 average flows ranged from $0.17/gpd for McPherson, to $2.88/gpd for Monticello-White Oaks Resort. Buckingham, which had a flow averaged cost of $1.76/gpd, had operating costs of $234,058. These costs included $61,400 in sludge disposal fees and $39,800 in engineering services fees, among other numerous itemized expenditures. By comparison, the operating costs supplied for McPherson included only labor, utilities, maintenance, chemicals, and supplies.

Separate utility costs were available for four plants. Utility costs ranged from $0.06 to $.55/gpd actual flow. The range of utility costs is probably most affected by the difference in electricity costs between different regions of the United States.

SECTION 7.

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APPENDIX A

Monthly Average Tables and Chronological Plots
for Wastewater Treatment Plants Providing Data

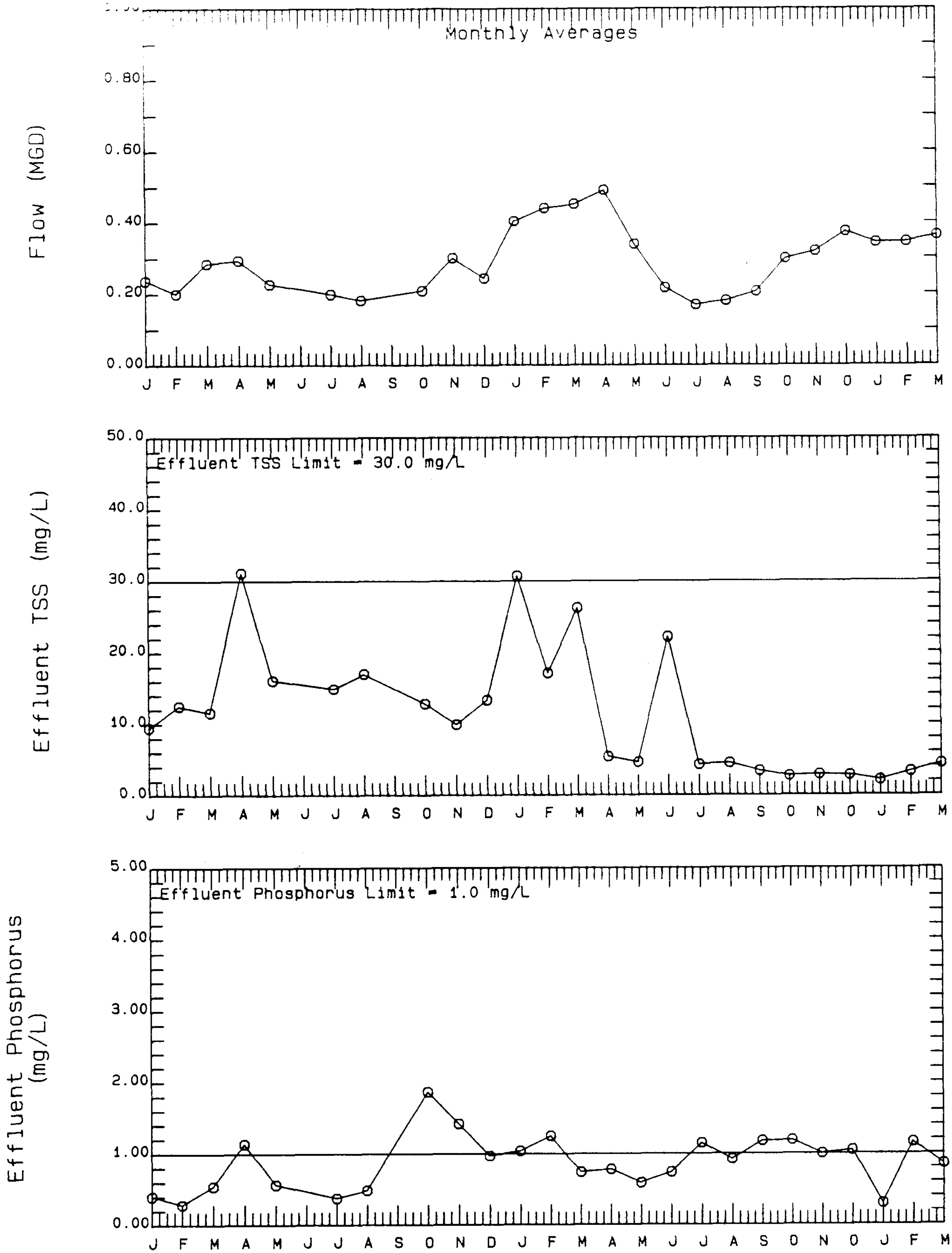
Armada, Michigan
Buckingham, Pennsylvania
Caledonia Minnesota
Clarkston, Michigan (Chateau Estates - manufacturer's data only)
Conover, North Carolina (Southeast Plant)
Del City, Oklahoma
Dundee, Michigan
Fairchance, Pennyslvania
Grafton, Ohio
Grundy Center, Iowa (manufacturer's data only)
Manchester, Michigan
Marlette, Michigan
McPherson, Kansas
Mifflinburg, Pennyslvania (manufacturer's data only)
Monticello, Indiana (White Oaks Resort)
Muskegon Heights, Michigan (Clover Estates - manufacturer's data only)
Shelter Island, New York
Walnut Grove, New York
Windgap, Pennsylvania (manufacturer's data only)

Armada Monitoring Data
monthly averages taken from DMR profile

Month	Flow MGD	Effluent TSS mg/l	Effluent P mg/l
Jan 1989	0.237	9.5	0.41
Feb 1989	0.200	12.5	0.29
Mar 1989	0.285	11.6	0.55
Apr 1989	0.294	31.1	1.14
May 1989	0.227	16.1	0.57
Jun 1989			
Jul 1989	0.199	14.9	0.38
Aug 1989	0.181	17.0	0.49
Sep 1989			
Oct 1989	0.209	12.8	1.87
Nov 1989	0.301	9.9	1.42
Dec 1989	0.243	13.3	0.97
Jan 1990	0.404	30.7	1.04
Feb 1990	0.441	17.1	1.25
Mar 1990	0.452	26.2	0.74
Apr 1990	0.491	5.4	0.78
May 1990	0.339	4.6	0.59
Jun 1990	0.216	22.2	0.74
Jul 1990	0.169	4.3	1.15
Aug 1990	0.180	4.5	0.92
Sep 1990	0.206	3.4	1.18
Oct 1990	0.298	2.7	1.19
Nov 1990	0.319	2.9	1.00
Dec 1990	0.374	2.8	1.05
Jan 1991	0.343	2.1	0.30
Feb 1991	0.345	3.3	1.16
Mar 1991	0.363	4.4	0.85
Minimum	0.169	2.1	0.29
Maximum	0.491	31.1	1.87
Average	0.293	11.4	0.88
Limit	NA	30.0	1.00

*Blank spaces indicate data which was not available.

Armada



January 1989 through March 1991

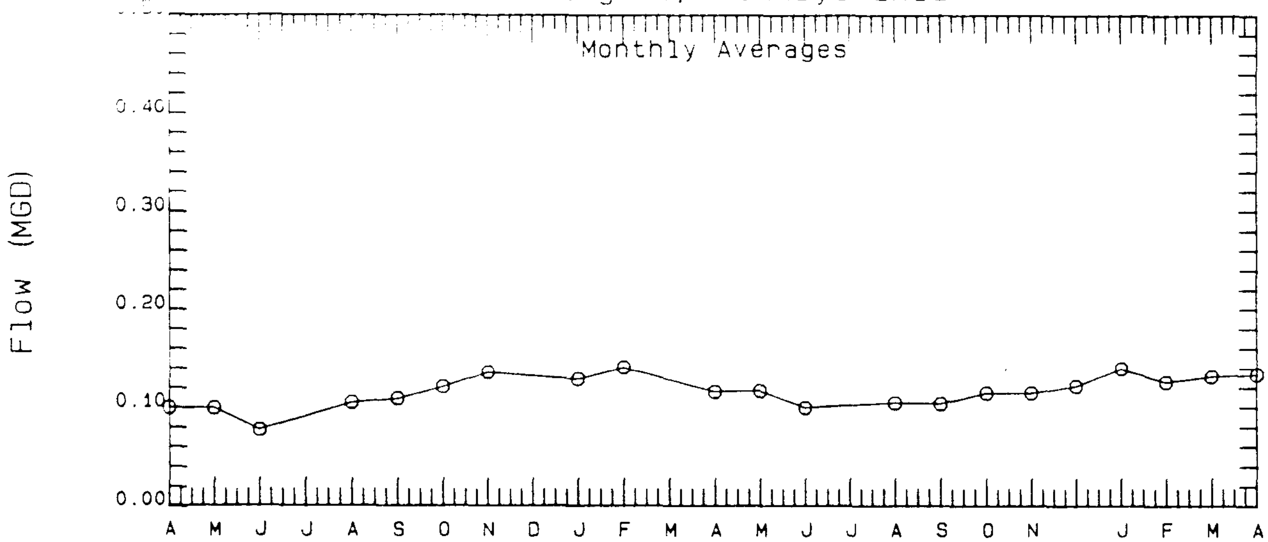
BUCKINGHAM, PENNSYLVANIA

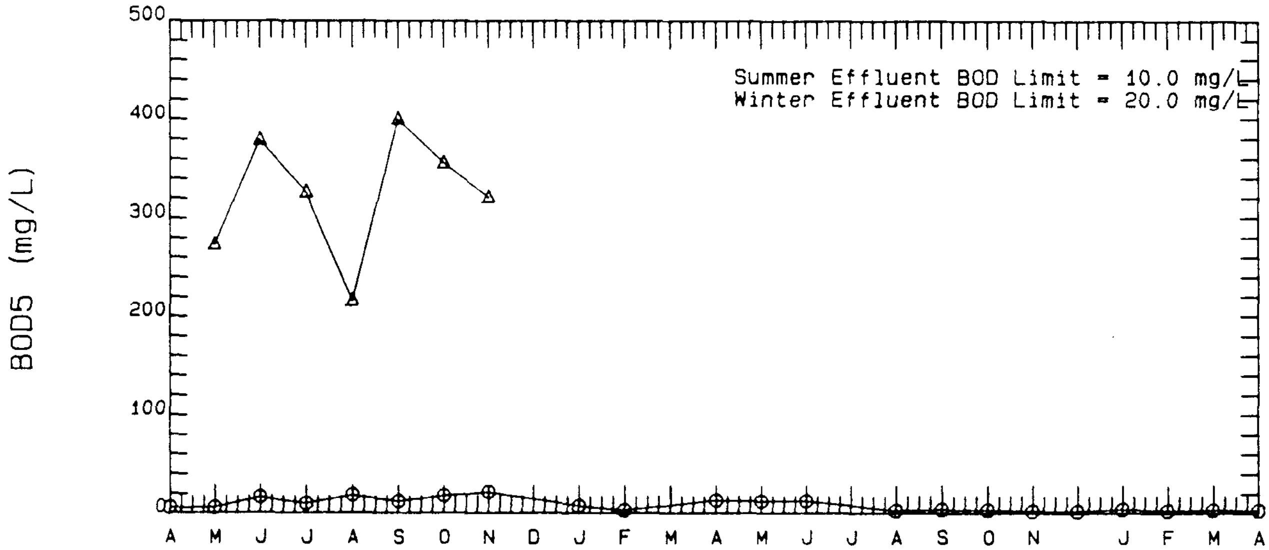
Monthly Averages

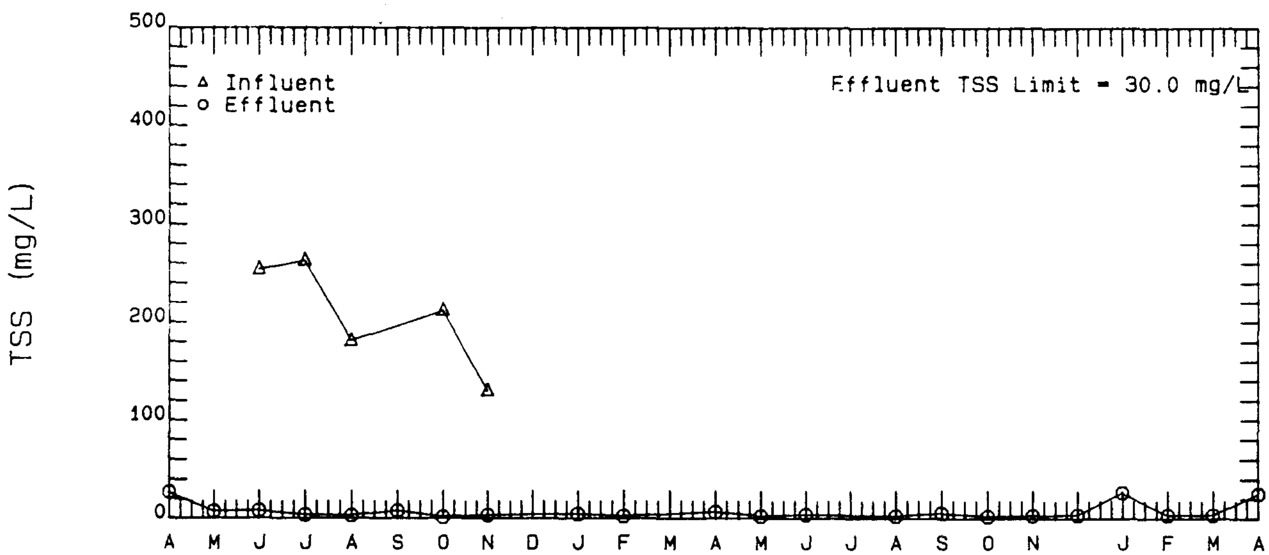
Date	Flow MGD	Influent BOD (mg/L)	Effluent BOD (mg/L)	Effluent TSS (Lbs/d)	Influent TKN (mg/L)	Effluent TKN (mg/L)	Influent NH3-N (mg/L)	Effluent NH3-N (mg/L)	Effluent NO2 & NO3 (mg/L)	Influent P (mg/L)	Effluent P (mg/L)	Influent TSS (mg/l)
489	0.099		5.04	26.5				2				
589	0.099	272.7	5.7	7.2	70.3	7.51	15.1	0.9	3.9	12.3	4.6	
689	0.077	379	16.6	7.9	63.2	5.62	21.6	1.43	0.79			254
789		325.9	9.88	3.5	66.2	23.4	28	2.41	0.6	11.9	6	263
889	0.105	215.3	18.8	2.8	62.9	9.3	27.9	0.93	0.65	11.3	3.3	181
989	0.109	399.6	12.1	7.8	62.3	7.5	31.0	0.25	3.9	14.7	6.7	
1089	0.121	355.5	18.1	1.3	81.75	16.5	25.5	1.07	0.73	12.6	4	212
1189	0.136	320.4	22.16	3.4			28.2	0.76	.66	8.9	3.94	130
1289												
190	0.129		7.25	4.8				0.35				
290	0.141		2.81	2.33				0.25				
390												
490	0.116		13.5	6.9				3.03				
590	0.117		12.5	2.5				3.5				
690	0.0998		12.8	3.98				3.44			1.27	
790												
890	0.105		2.8	2.5				0.1	5.35		4.8	
990	0.104		3.8	5.5				0.2	2.9		4.6	
1090	0.115		3.3	2.3				0.6	2.1		3.2	
1190	0.115		2	3				0.2	3		5.1	
1290	0.122		2	3.8				0.4	2.03		2.8	
191	0.14		4.2	27				0.2	1.9		2.9	
291	0.126		2.8	3.5				1.3	1.3		3	
391	0.132		3.3	3.5				0.1	2.8		3.7	
491	0.134		3.2	25.4				0.1	1.2		4.5	
/*												
AVG =	0.116	324.057	8.393	7.155	67.775	11.638	25.329	1.069	2.113	11.950	4.026	208.
STD =	0.016	63.504	6.364	8.007	7.468	6.897	5.365	1.112	1.426	1.889	1.327	
MAX =	0.141	399.600	22.160	27.000	81.750	23.400	31.000	3.500	5.350	14.700	6.700	
MIN =	0.077	215.300	2.000	1.300	62.300	5.620	15.100	0.100	0.600	8.900	1.270	

Buckingham, Pennsylvania

Monthly Averages

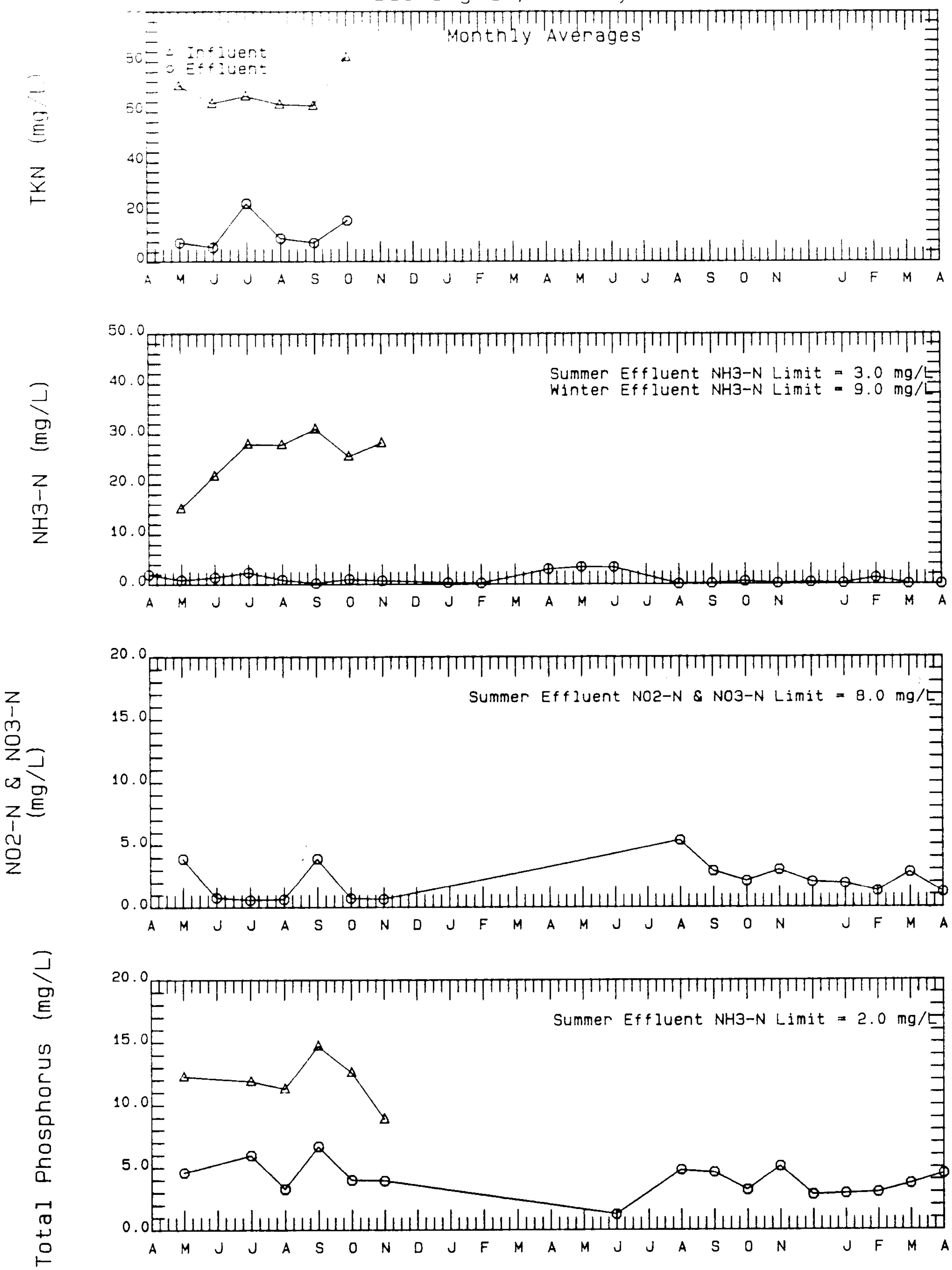






April 1989 through April 1991

Buckingham, Pennsylvania

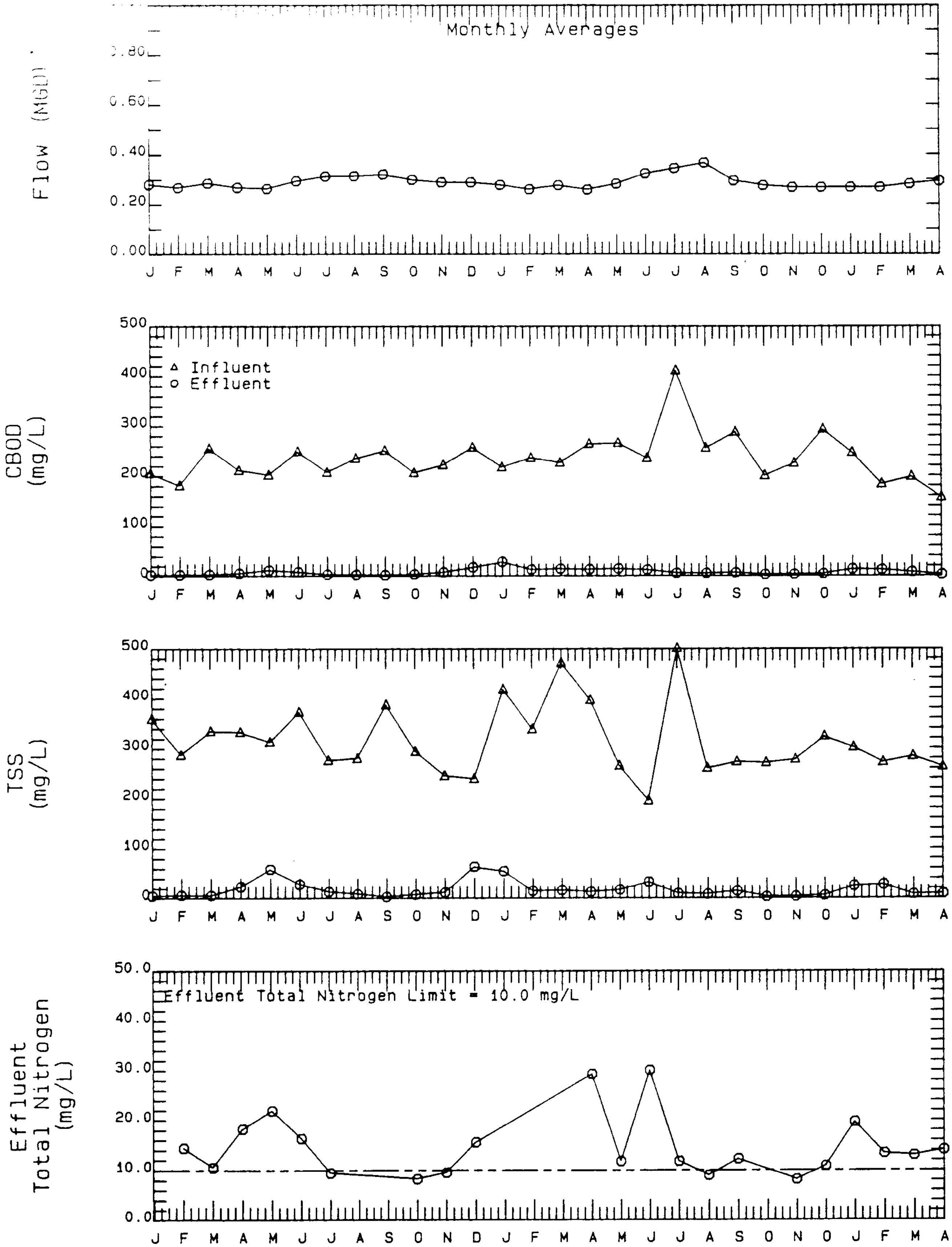


April 1989 through April 1991

Caledonia Monitoring Data
monthly averages taken from DMR profile

Month	Flow MGD	Influent TSS mg/l	Effluent TSS mg/l	Influent CBOD mg/l	Effluent CBOD mg/l	Effluent TN mg/l
Apr 1988	0.271	224	16.0	243	8.6	
May 1988	0.278	146	13.5	199	8.8	
Jun 1988	0.336	164	7.5	180	4.5	
Jul 1988	0.325	195	4.0	177	2.3	
Aug 1988	0.348	195	2.9	233	2.4	
Sep 1988	0.327	215	4.2	200	2.3	5.9
Oct 1988	0.302	230	5.0	171	2.3	6.1
Nov 1988	0.306	198	6.0	216	2.5	7.5
Dec 1988	0.284	234	4.2	256	2.7	11.0
Jan 1989	0.280	359	5.4	205	2.7	
Feb 1989	0.267	287	6.5	181	3.2	14.5
Mar 1989	0.286	335	6.0	255	3.8	10.6
Apr 1989	0.268	333	23.6	211	6.0	18.3
May 1989	0.264	313	58.7	202	12.7	22.0
Jun 1989	0.295	373	28.6	249	8.7	16.4
Jul 1989	0.314	276	13.5	207	3.8	9.5
Aug 1989	0.315	280	8.9	235	3.5	
Sep 1989	0.321	387	3.1	251	2.5	
Oct 1989	0.299	294	7.5	206	4.0	8.3
Nov 1989	0.289	245	12.2	222	8.2	9.6
Dec 1989	0.289	239	64.0	257	18.0	15.6
Jan 1990	0.279	418	55.0	217	29.0	
Feb 1990	0.261	338	14.8	236	13.2	
Mar 1990	0.278	471	16.4	226	15.0	
Apr 1990	0.260	396	13.0	264	13.6	29.3
May 1990	0.284	265	17.2	266	15.0	11.8
Jun 1990	0.325	195	33.0	235	13.0	30.1
Jul 1990	0.346	500	10.0	411	5.8	11.8
Aug 1990	0.368	260	8.4	255	5.4	9.0
Sep 1990	0.296	273	15.0	288	6.8	12.3
Oct 1990	0.277	271	3.3	200	3.1	
Nov 1990	0.269	278	3.8	225	3.8	8.2
Dec 1990	0.269	324	6.0	293	4.5	10.9
Jan 1991	0.269	302	25.0	246	14.0	19.7
Feb 1991	0.269	272	28.0	183	13.0	13.4
Mar 1991	0.283	284	8.0	198	8.0	13.0
Apr 1991	0.295	263	9.0	157	3.0	14.1
Minimum	0.260	146	2.9	157	2.3	5.86
Maximum	0.368	500	64.0	411	29.0	30.08
Average	0.294	287	15.3	229	7.6	13.5
Limit	NA	NA		NA		10.0

Caledonia



January 1989 through April 1991

CHATEAU ESTATES
Clarkston , Michigan

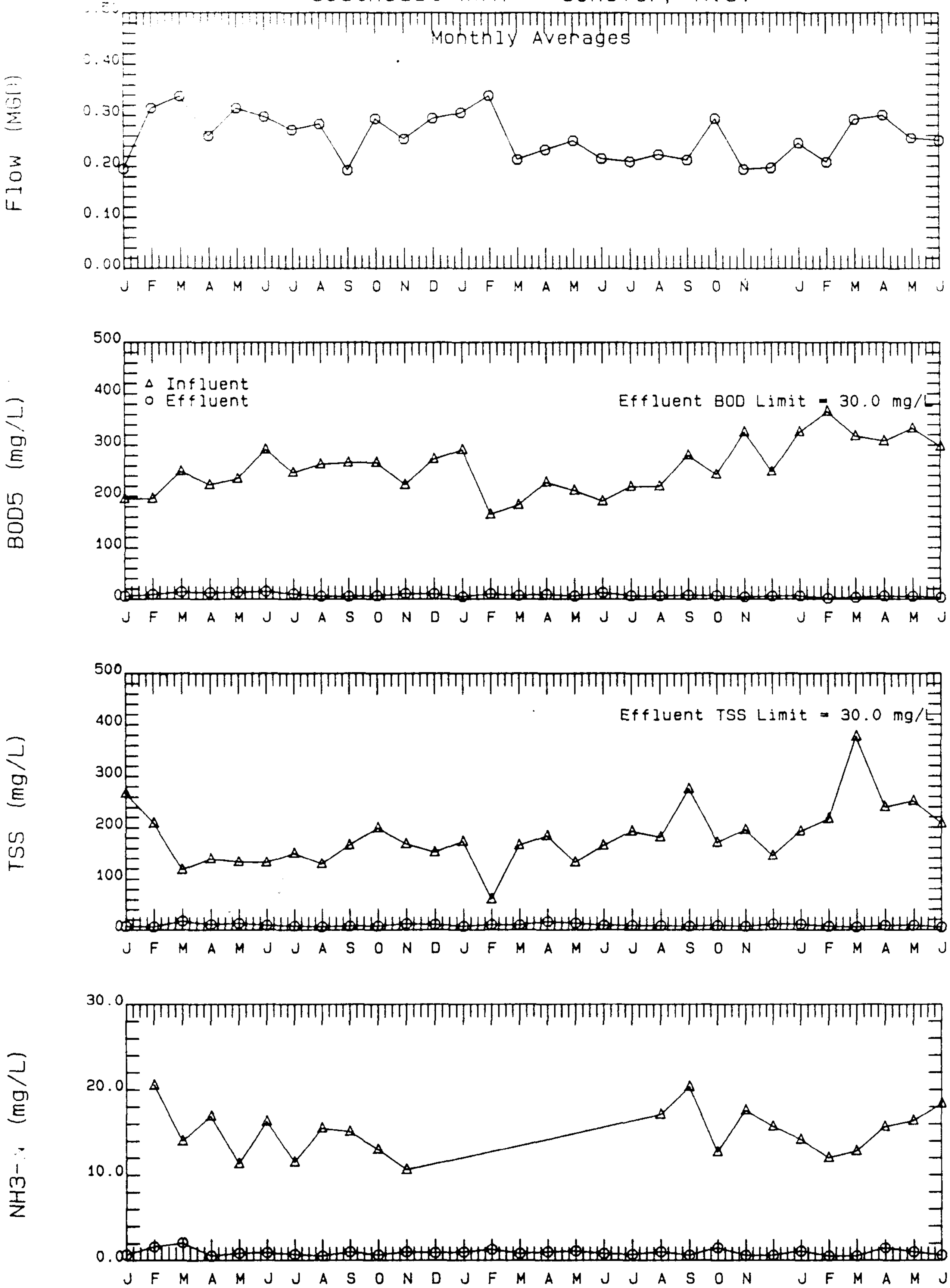
DATE	FLOW	INFLUENT			EFFLUENT						MIXED LIQUOR		
(Month/ Year)	(MGD)	BOD_5 (mg/l)	TSS (mg/l)	NH_3-N (mg/l)	BOD_5 (mg/l)	TSS (mg/l)	NH_3-N (mg/l)	NO_2-N (mg/l)	NO_3-N (mg/l)	Total Inorganic-N (mg/l)	MLSS (mg/ l)	MLVSS (mg/l)	F/M (Day^{-1})
11-89	0.0480	----	----	----	19.3	18.5	2.72	0.18	3.5	6.40	1987	1567	----
12-89	0.0537	212	313	34	9.8	2.5	1.08	0.21	6.1	7.39	2863	2170	0.042
1-90	0.0540	168	275	36	7.1	4.2	0.58	0.11	4.0	4.69	2618	2032	0.041
2-90	----	----	----	----	----	----	----	----	----	----	----	----	----
3-90	0.0618	186	163	----	8.7	2.7	0.60	0.10	2.68	3.38	2993	2340	0.044
4-90	0.0587	194	238	----	7.4	2.3	0.23	0.13	3.10	3.46	2544	1961	0.052
5-90	0.0588	152	277	----	17.4	7.3	0.38	0.22	3.60	4.20	3371	2207	0.031
6-90	0.0590	171	192	----	14.2	12.7	2.87	0.20	2.32	5.39	5057	2717	0.023
7-90	0.0553	175	395	----	5.6	1.5	2.35	0.02	1.32	3.69	4480	2572	0.025
8-90	0.0531	169	292	----	4.9	2.5	2.64	0.06	3.75	6.45	3630	2274	0.029
9-90	0.0564	192	212	----	3.7	2.4	2.94	0.03	1.80	4.77	3015	2071	0.042
10-90	0.0540	241	482	----	14.5	7.3	0.25	0.02	1.34	1.61	1846	1396	0.082
11-90	0.0540	189	159	----	8.0	3.2	1.01	----	----	----	1879	1556	0.064
12-90	0.0540	206	223	41	6.4	1.4	0.42	0.04	1.13	1.59	3752	2938	0.035
1-91	0.0540	218	269	57	6.7	6.1	2.01	0.19	4.05	6.25	2860	2262	0.048
2-91	0.0540	157	179	30	13.1	8.3	2.78	0.27	5.64	8.69	3332	2607	0.030
3-91	0.0540	236	251	33	45.7	30.1	4.18	0.16	2.17	6.51	3642	2835	0.041
4-91	0.0540	212	240	43	18.7	13.1	1.57	0.09	1.20	2.86	4256	3278	0.031
Average Values	0.0551	192	260	39.1	12.4	7.4	1.68	0.13	2.98	4.83	3184	2281	0.041
Design Values	0.110	220	220	25	30	30	----	----	----	5.0	3496	2447	0.07

CONOVER, NORTH CAROLINA - SOUTHEAST PLANT

Monthly Averages

Date	Influent BOD (mg/L)	Influent NH3 (mg/L)	Influent TSS (mg/L)	Flow (MGD)	Effluent BOD (mg/L)	Effluent NH3 (mg/L)	Effluent TSS (mg/L)	Eff TN (mg/L)	Eff TP (mg/l)
189	195.0		267.0	0.195	6.0	0.66	8.0		
289	195.0	20.5	208.0	0.314	9.2	1.60	6.6	11.4	1.40
389	248.8	14.0	117.3	0.337	14.5	2.10	17.8		
489	222.0	16.9	139.0	0.259	13.0	0.53	10.9		
589	234.0	11.3	133.0	0.314	13.9	0.85	13.3	10.4	1.40
689	292.0	16.3	132.0	0.297	15.5	0.92	9.6		
789	246.0	11.5	150.0	0.271	10.8	0.69	7.8		
889	263.0	15.5	129.0	0.283	6.0	0.50	6.5		
989	266.0	15.1	166.0	0.192	5.7	1.00	7.9	1.4	0.90
1089	266.0	13.0	199.0	0.293	6.8	0.63	7.9		
1189	222.0	10.6	168.0	0.253	11.4	1.00	12.3	5.1	1.50
1289	273.0		152.0	0.294	10.7	0.90	10.9		
190	291.0		173.0	0.305	4.7	0.97	7.3		
290	164.6		60.3	0.338	10.7	1.30	10.6	3.6	0.15
390	183.0		166.0	0.213	7.2	0.80	10.1		
490	227.0		184.0	0.232	9.7	1.00	17.0		
590	211.0		132.0	0.250	6.1	1.10	13.6	5.44	0.72
690	190.0		165.0	0.215	13.0	0.80	9.3		
790	218.7		193.0	0.209	6.9	0.70	9.0		
890	219.3	17.1	181.1	0.223	6.5	1.00	8.5		
990	280.0	20.3	275.2	0.212	7.7	0.60	7.3		
1090	242.2	12.7	170.7	0.293	7.1	1.50	9.2		
1190	325.5	17.6	195.8	0.194	4.5	0.60	7.3		
1290	248.0	15.7	144.8	0.197	5.8	0.60	11.8		
191	325.6	14.2	193.0	0.245	6.6	1.10	11.5		
291	365.9	12.0	216.9	0.208	2.0	0.50	7.2		
391	317.4	12.8	377.0	0.292	3.8	0.50	6.0		
491	307.3	15.7	240.0	0.300	6.1	1.50	9.1		
591	332.9	16.4	252.0	0.255	5.8	1.00	9.3		
691	297.4	18.4	207.4	0.250	3.4	0.60	5.7		
/*									
SUM =	7669.6	317.6	5487.5	7.733	241.1	27.55	289.3		
AVG =	255.7	15.1	182.9	0.258	8.0	0.92	9.6		
STD =	49.6	2.8	58.0	0.044	3.5	0.38	2.9		
MAX =	365.9	20.5	377.0	0.338	15.5	2.10	17.8		
MIN =	164.6	10.6	60.3	0.192	2.0	0.50	5.7		

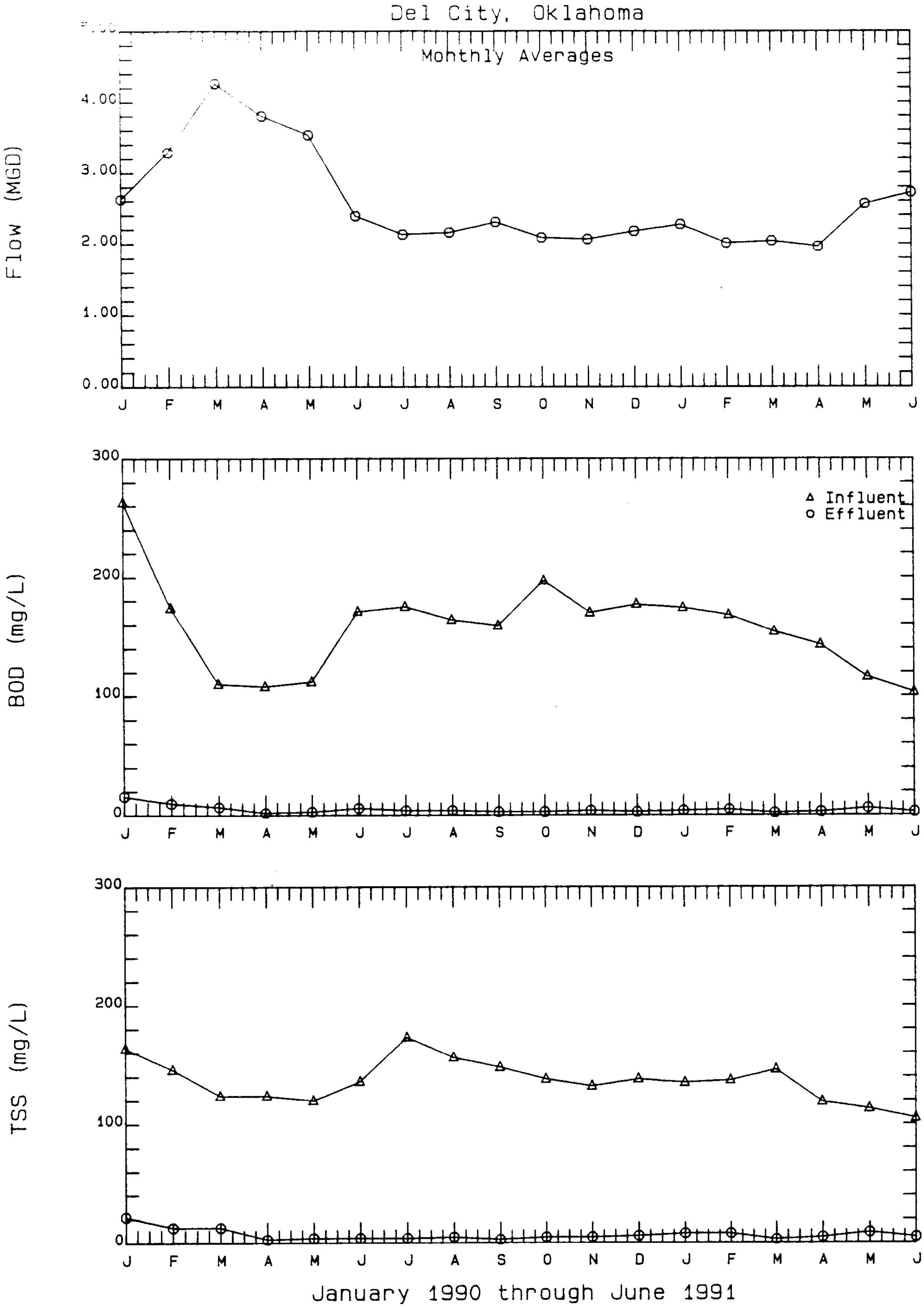
Southeast WWTP - Conover, N.C.

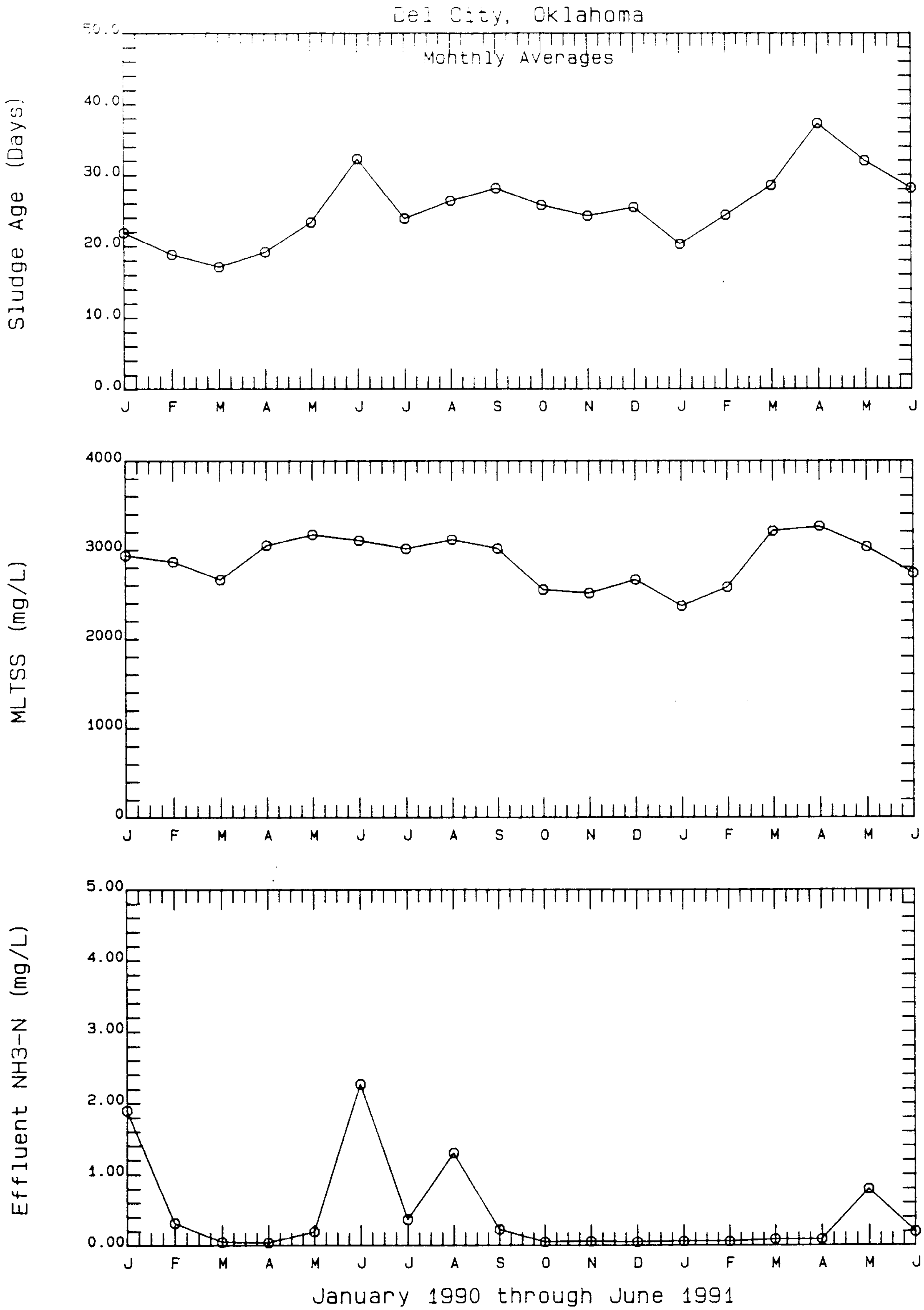


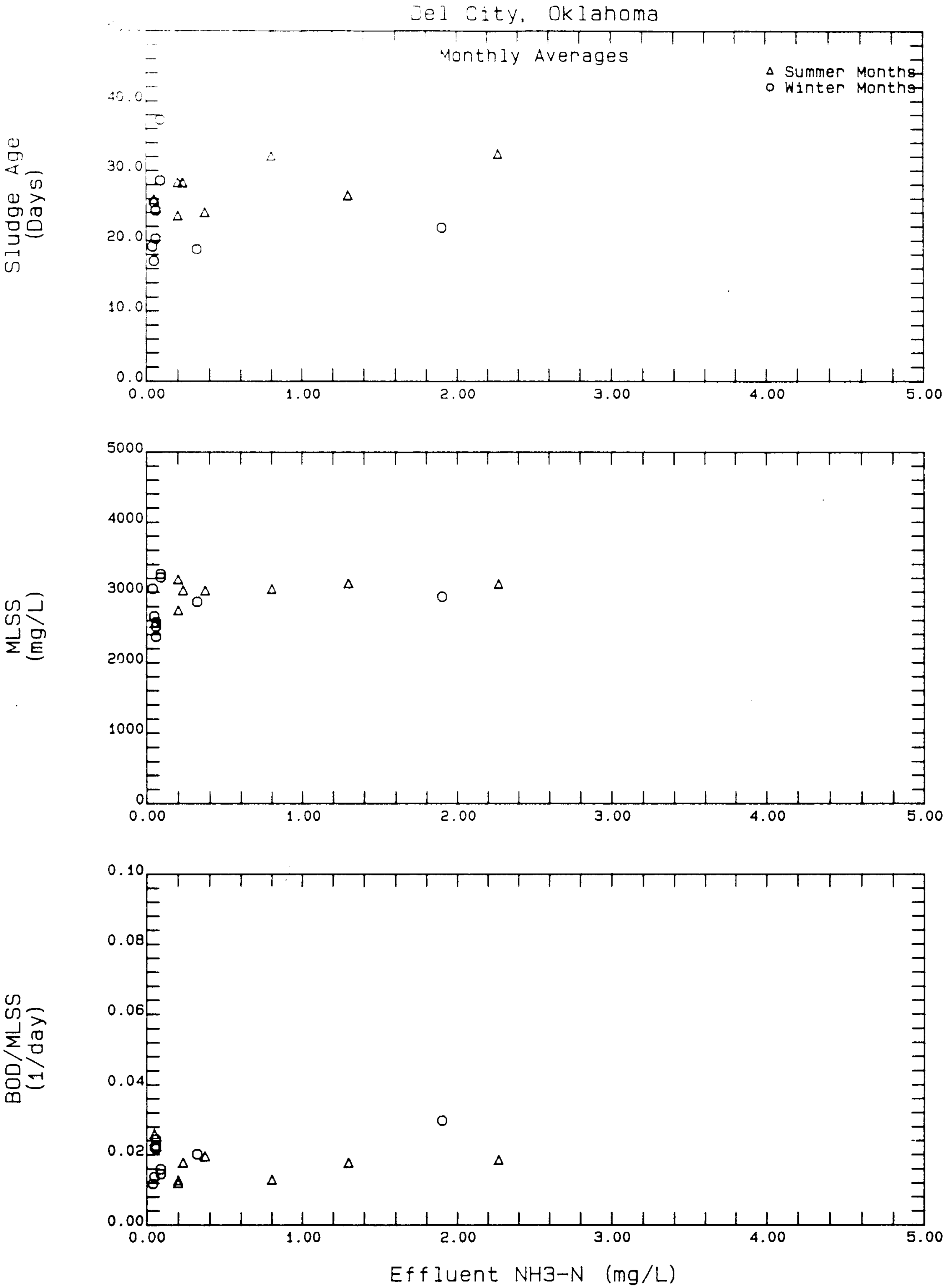
DEL CITY, OKLAHOMA

Monthly Averages

Date	Flow MGD	Influent TSS (mg/L)	Influent BOD (mg/L)	Sludge Age (Days)	MLTSS (mg/L)	Effluent TSS (mg/L)	Effluent BOD (mg/L)	Effluent NH3-N (mg/L)
190	2.629	164	263	21.9	2939	22	16	1.90
290	3.292	146	174	18.8	2867	13	10	0.32
390	4.263	124	110	17.1	2663	13	7	0.05
490	3.806	124	108	19.2	3051	3	2	0.04
590	3.537	120	112	23.4	3172	4	3	0.20
690	2.396	136	171	32.3	3105	4	6	2.27
790	2.135	173	175	23.9	3012	4	4	0.37
890	2.163	156	164	26.4	3115	5	4	1.30
990	2.309	148	159	28.2	3014	3	3	0.23
1090	2.091	138	197	25.8	2552	5	3	0.05
1190	2.068	132	170	24.3	2513	5	4	0.06
1290	2.179	138	177	25.5	2663	6	3	0.05
191	2.273	135	174	20.3	2371	8	4	0.06
291	2.012	137	168	24.4	2580	8	5	0.06
391	2.043	146	154	28.6	3213	3	2	0.09
491	1.962	119	143	37.3	3265	5	3	0.09
591	2.564	113	116	32.0	3034	9	6	0.80
691	2.726	105	103	28.2	2735	5	3	0.20
/*								
SUM =	46.448	2454	2838	457.6	51864	125	88	8.14
AVG =	2.580	136	158	25.4	2881	7	5	0.45
STD =	0.667	17	38	5.0	263	5	3	0.66
MAX =	4.263	173	263	37.3	3265	22	16	2.27
MIN =	1.962	105	103	17.1	2371	3	2	0.04


Del City, Oklahoma
Monthly Averages
Flow (MGD)
0.00
1.00
2.00
3.00
4.00
J F M A M J J A S O N D J F M A M J
BOD (mg/L)
0
100
200
300
Influent
Effluent
J F M A M J J A S O N D J F M A M J
TSS (mg/L)
0
100
200
300
J F M A M J J A S O N D J F M A M J
January 1990 through June 1991


Del City, Oklahoma
Mohtnly Averages
Sludge Age (Days)
50.0
40.0
30.0
20.0
10.0
0.0
J F M A M J J A S O N D J F M A M J
MLTSS (mg/L)
4000
3000
2000
1000
0
J F M A M J J A S O N D J F M A M J
Effluent NH3-N (mg/L)
5.00
4.00
3.00
2.00
1.00
0.00
J F M A M J J A S O N D J F M A M J
January 1990 through June 1991

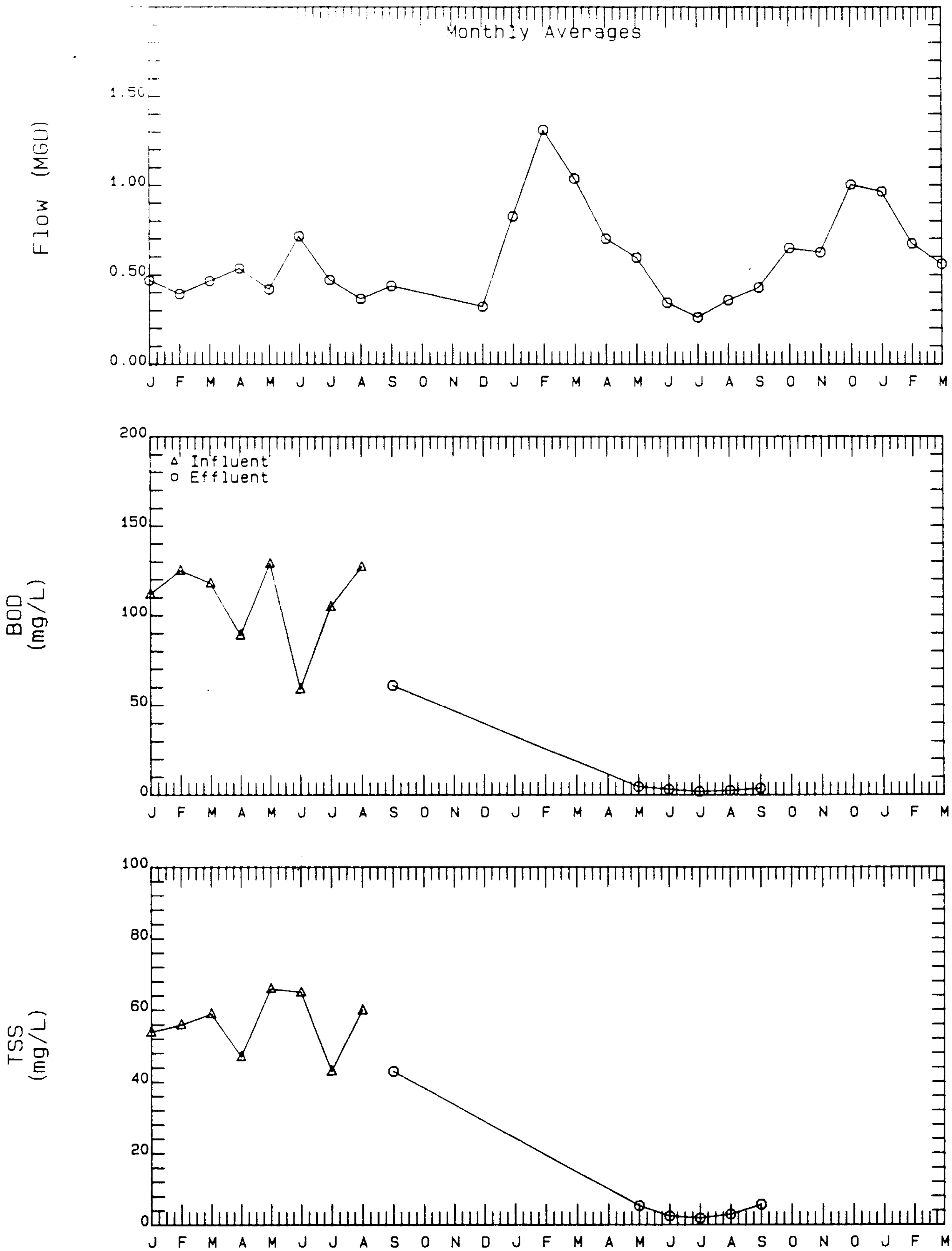

Del City, Oklahoma
Monthly Averages
Summer Months
Winter Months
Sludge Age (Days)
0.0
10.0
20.0
30.0
40.0
MLSS (mg/L)
0
1000
2000
3000
4000
5000
BOD/MLSS (1/day)
0.00
0.02
0.04
0.06
0.08
0.10
0.00
1.00
2.00
3.00
4.00
5.00
Effluent NH3-N (mg/L)

Dundee Monitoring Data
monthly averages taken from DMR profile

Month	Flow MGD	Influent TSS mg/l	Effluent TSS mg/l	Effluent P mg/l	Influent BOD mg/l	Effluent BOD mg/l	Effluent NH3-N mg/l
Jan 1989	0.470	54			112		
Feb 1989	0.394	56			125		
Mar 1989	0.466	59			118		
Apr 1989	0.537	47			89		
May 1989	0.420	66			129		
Jun 1989	0.715	65			59		
Jul 1989	0.473	43			105		
Aug 1989	0.367	60			127		
Sep 1989	0.439		43.0	1.70		61.0	
Oct 1989				1.20			
Nov 1989				0.70			
Dec 1989	0.324			1.20			
Jan 1990	0.827			0.80			
Feb 1990	1.311			0.40			
Mar 1990	1.039			0.60			
Apr 1990	0.701			0.30			
May 1990	0.595		5.4	0.40		4.7	2.3
Jun 1990	0.345		2.5	0.50		3.2	1.7
Jul 1990	0.263		1.9	0.60		2.0	1.4
Aug 1990	0.359		3.0	0.20		2.5	1.2
Sep 1990	0.429		5.7	0.35		3.8	2.1
Oct 1990	0.649			0.40			
Nov 1990	0.625			0.50			
Dec 1990	1.004			0.50			
Jan 1991	0.964			0.30			
Feb 1991	0.673			0.30			
Mar 1991	0.560			0.20			
Minimum	0.263	43	1.9	0.20	59	2.0	1.2
Maximum	1.311	66	43.0	1.70	129	61.0	2.3
Average	0.598	56	10.3	0.59	108	12.9	1.7
Limit	NA	NA		0.50	NA		

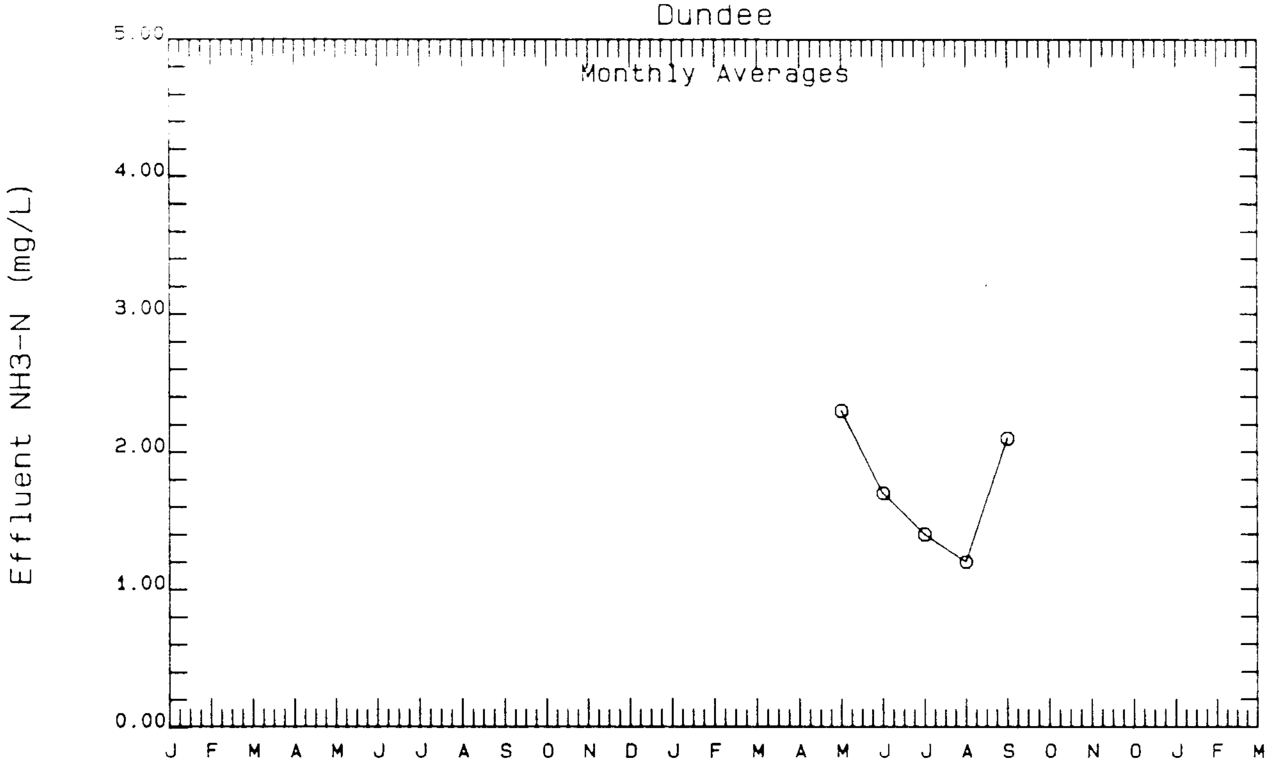
NOTES:
1. SBR system began operation on September 21, 1989. The summary does not include September 1989.
2. Blank spaces indicate data which was not available.

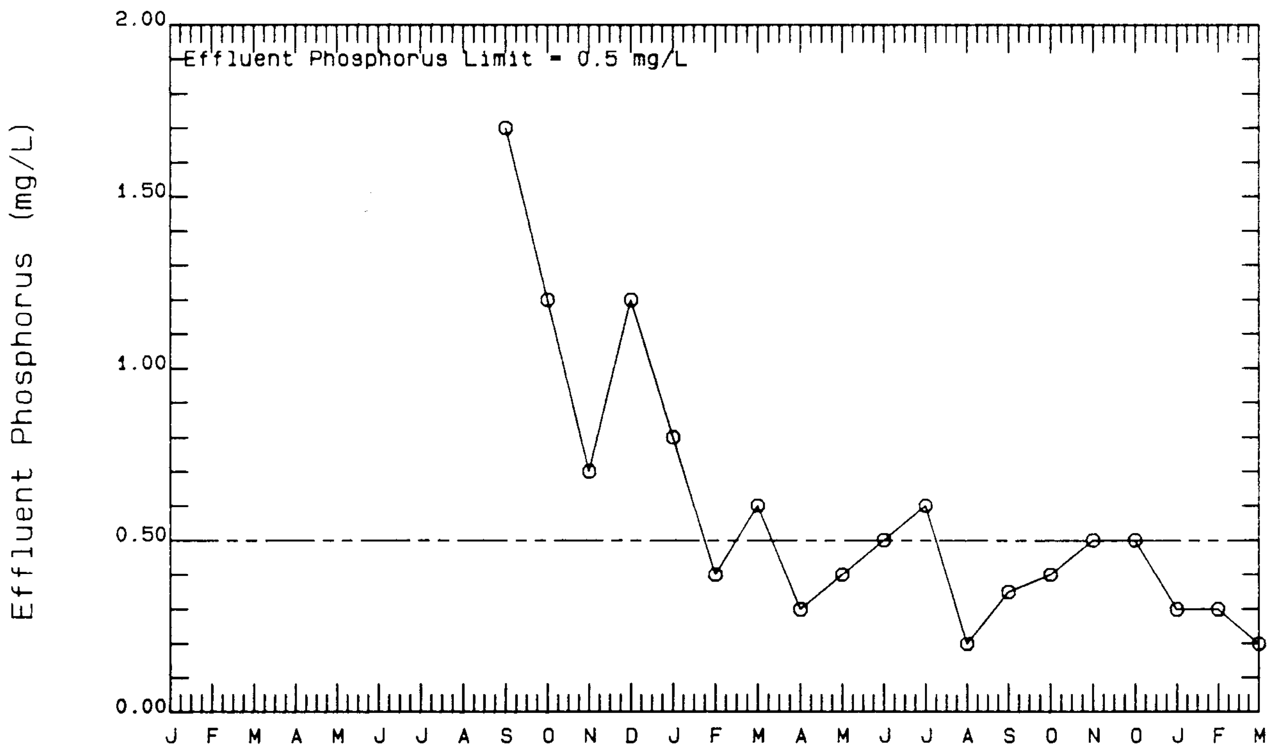
Dundee



January 1989 through March 1991

Dundee





January 1989 through March 1991

FAIRCHANCE-GEORGES
JOINT MUNICIPAL SEWAGE AUTHORITY

INFLUENT AND EFFLUENT DATA

EFFLUENT PERMIT LIMITS:

FLOW:	.350 Average Monthly	
BOD_5	15mg/l Average Monthly	
Suspended Solids	25mg/l Average Monthly	
NH_3-N	1.5mg/l Average Monthly	5/1 to 10/31
	5.0mg/l Average Monthly	11/1 to 4/30
D.O.	5.0mg/l minimum	
pH	6.0 to 9.0 SU	
Fecal Coliform	200/100mg/l Average Monthly	

DMR DATA:

1989	Limited data available
1990	
Flow	.180 Average Monthly
BOD_5	8mg/l Average Monthly
SS	10mg/l Average Monthly
NH_3N	.7mg/l Average Monthly
pH	6.9 to 7.3 SU
Fecal Coliform	Less than 10/100mg/l Average Monthly
1991	First six months
Flow	.210 Average Monthly
BOD_5	16mg/l Average Monthly
SS	15mg/l Average Monthly
NH_3-N	.2mg/l Average Monthly
pH	6.9 to 7.3 SU
Fecal Coliform	Less than 10/100mg/l Average Monthly

Influent data limited on ammonia nitrogen(NH_3-N)ranging from 1 to 2mg/l.

Grafton Monitoring Data
monthly averages taken from DMR profile

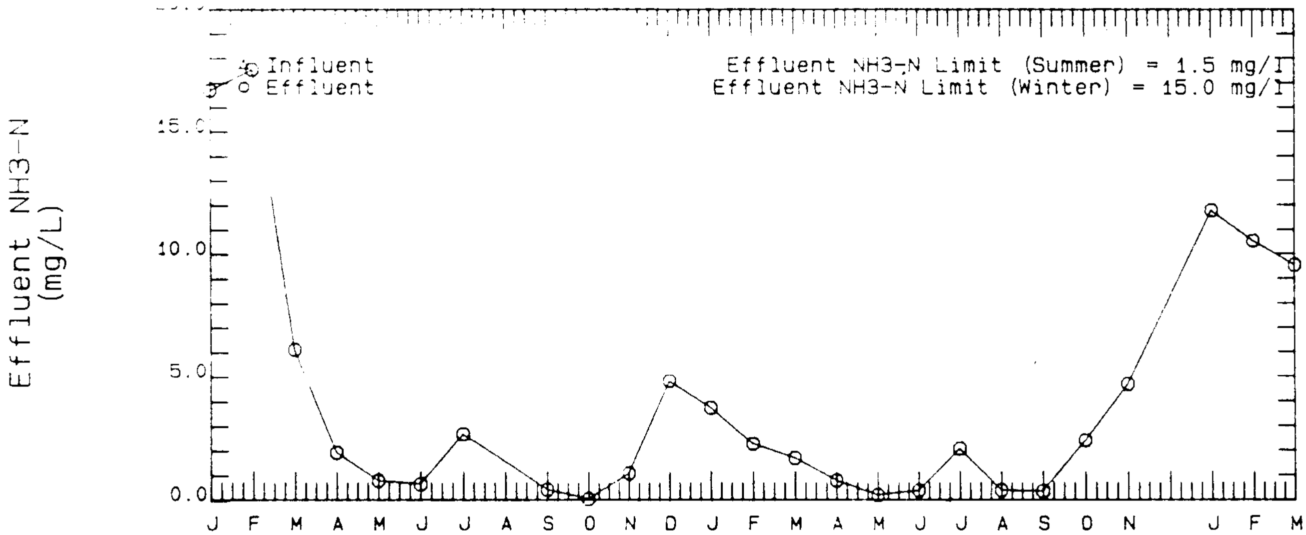
Month	Flow MGD	Influent CBOD mg/l	Effluent CBOD mg/l	Effluent NH3-N mg/l	Effluent NO3+NO2 mg/l	Effluent P mg/l	Effluent Temp deg C
Dec 1988	0.458	166	59.3				10.2
Jan 1989	0.734	146	9.0	16.70		1.48	9.8
Feb 1989	0.682	114	9.3	17.55		1.75	9.2
Mar 1989	0.832	102	5.9	6.09		1.68	10.3
Apr 1989	1.021	127	2.8	1.91		4.39	11.6
May 1989	0.554	73	4.3	0.77		1.72	14.3
Jun 1989	0.475	150	2.7	0.64		0.94	18.5
Jul 1989	0.329	142	3.0	2.68		1.44	21.6
Aug 1989							
Sep 1989	0.323	147	2.9	0.42	31.1	1.78	21.0
Oct 1989	0.309	125	2.6	0.04	3.1	2.10	18.4
Nov 1989	0.669	92	3.1	1.09	13.7	1.86	14.7
Dec 1989	0.299	134	10.7	4.83	5.3	1.83	10.2
Jan 1990	0.454	74	3.8	3.75	9.8	1.03	10.1
Feb 1990	0.549	73	3.0	2.28	11.2	0.78	10.0
Mar 1990	0.348	199	6.3	1.69	6.6	0.77	11.5
Apr 1990	0.497	87	2.6	0.78	1.0	1.19	12.6
May 1990	0.498	131	2.5	0.20	3.8	0.23	16.0
Jun 1990	0.446	188	4.9	0.38	1.2	1.73	19.7
Jul 1990	0.494	145	3.3	2.07	3.5	2.44	21.6
Aug 1990	0.488	137	3.2	0.39	3.9	2.19	22.2
Sep 1990	0.590	130	2.3	0.35	2.9	0.73	21.6
Oct 1990	0.592	107	1.7	2.42	2.6	0.57	18.7
Nov 1990	0.438	186	3.1	4.70	0.1	0.58	16.5
Dec 1990		133					
Jan 1991	0.508	112	3.0	11.80	0.4	0.63	11.4
Feb 1991	0.639	126	4.4	10.55	0.3	0.13	13.0
Mar 1991	0.618	160	5.0	9.57	0.2	1.08	11.5

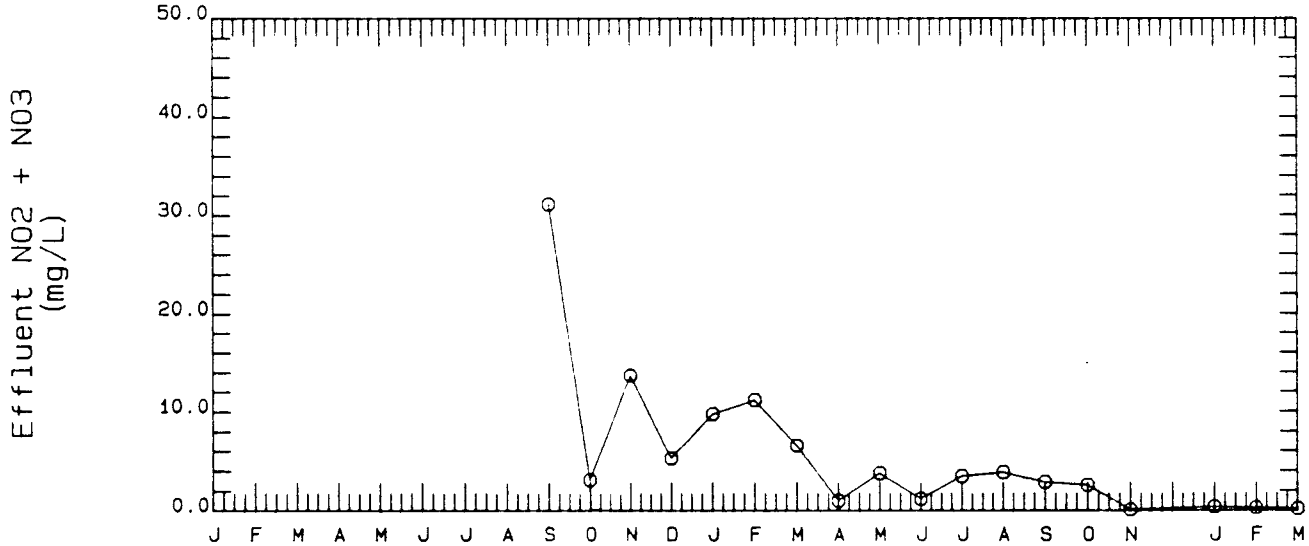
/*

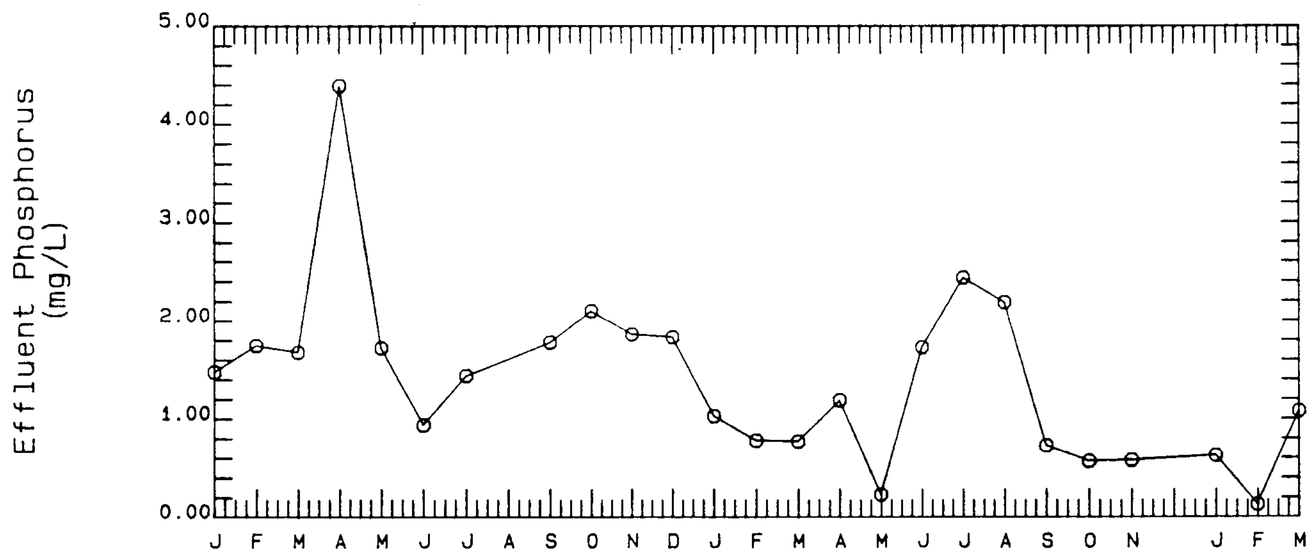
SUMMARY:							
Minimum	0.299	73	1.7	0.04	0.1	0.13	9.2
Maximum	1.021	199	10.7	11.80	31.1	4.39	22.2
Average	0.532	130	4.2	3.02	5.6	1.40	14.9
LIMITS:							
Winter	NA	NA	20.0	15.00	NA	NA	NA
Summer	NA	NA	15.0	1.50	NA	NA	NA

NOTES:
1. The Grafton SBR began operation in December of 1988. The effluent BOD concentration for December 1988 was omitted from the summary, as were the ammonia concentrations for the first three months of operation.
2. The ammonia concentrations during the winter were intentionally high because Grafton has a high ammonia limit in the winter.
3. Blank spaces indicate data which was not available.

Grafton, Ohio

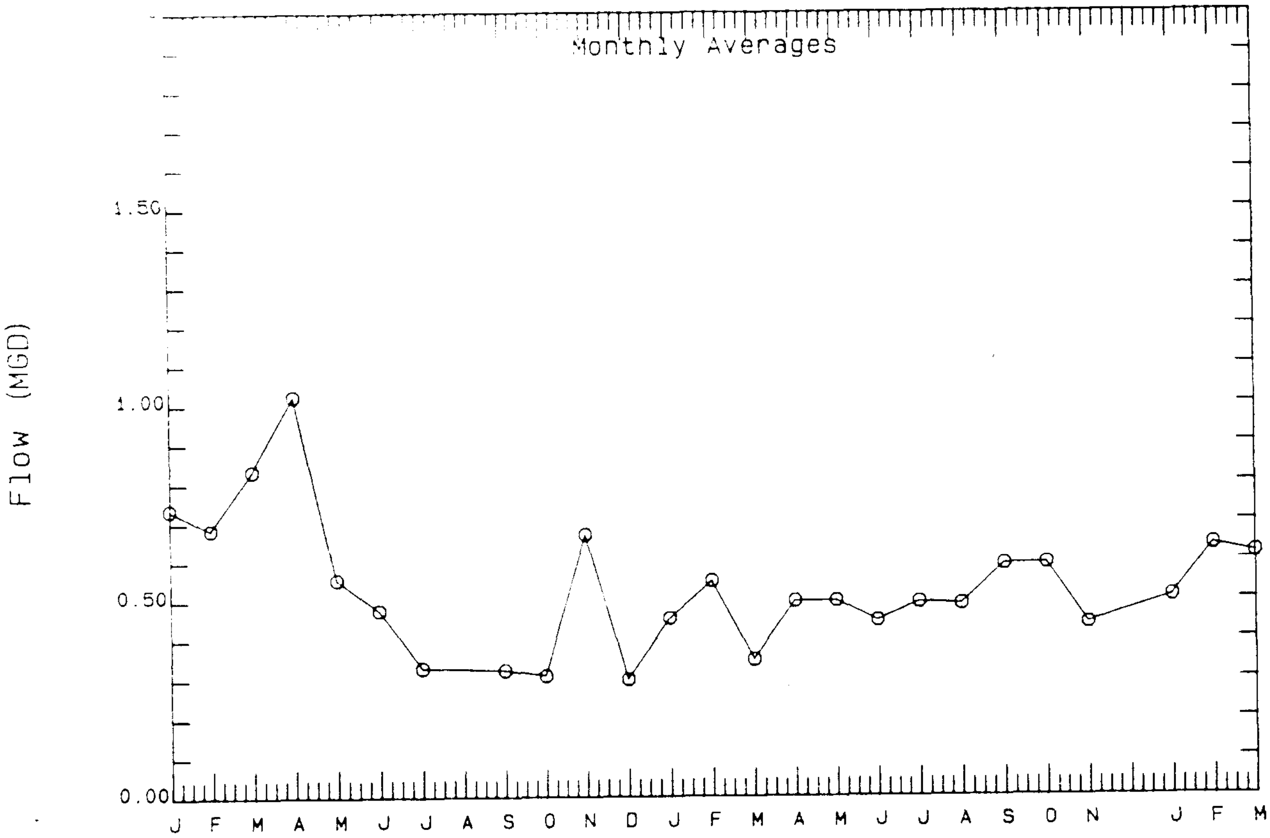


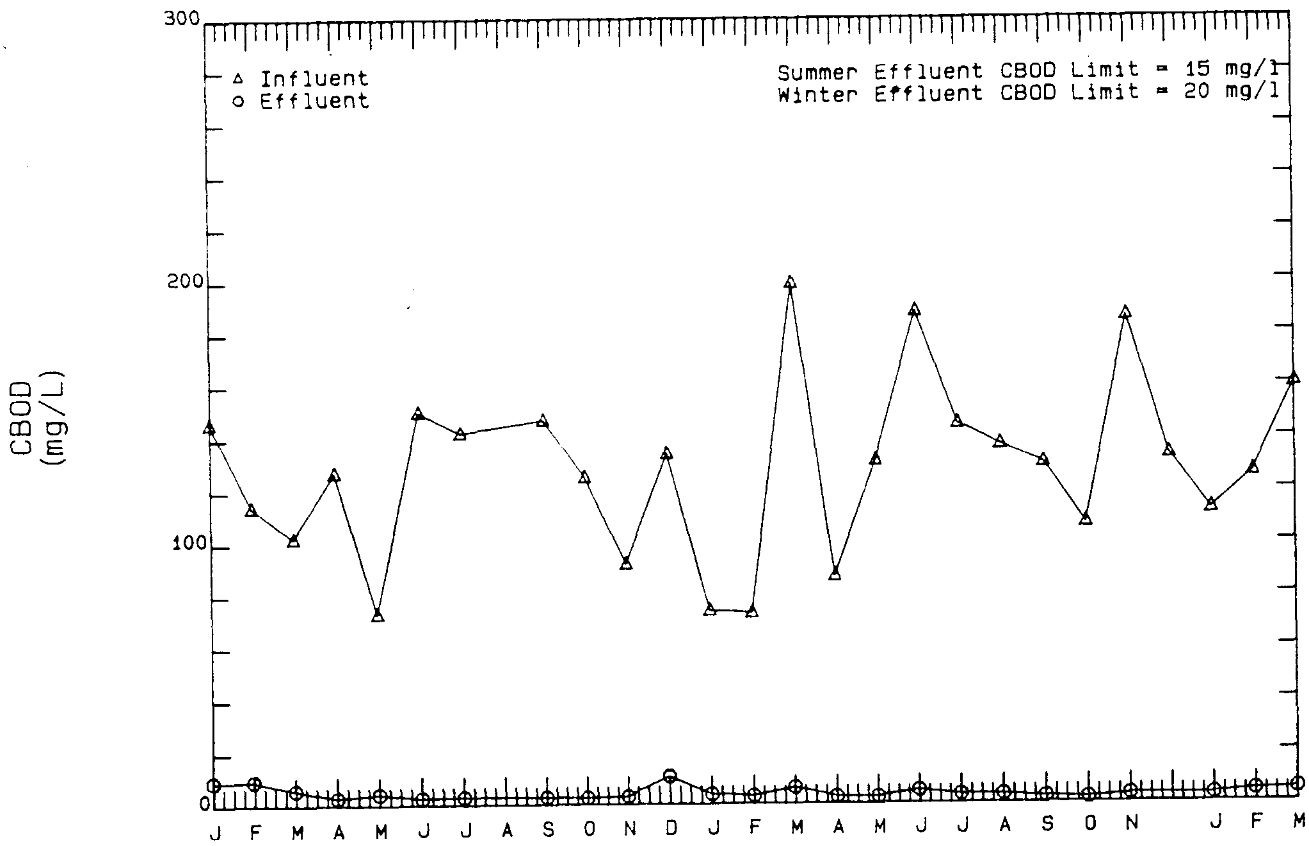




January 1989 through March 1991

Grafton, Ohio





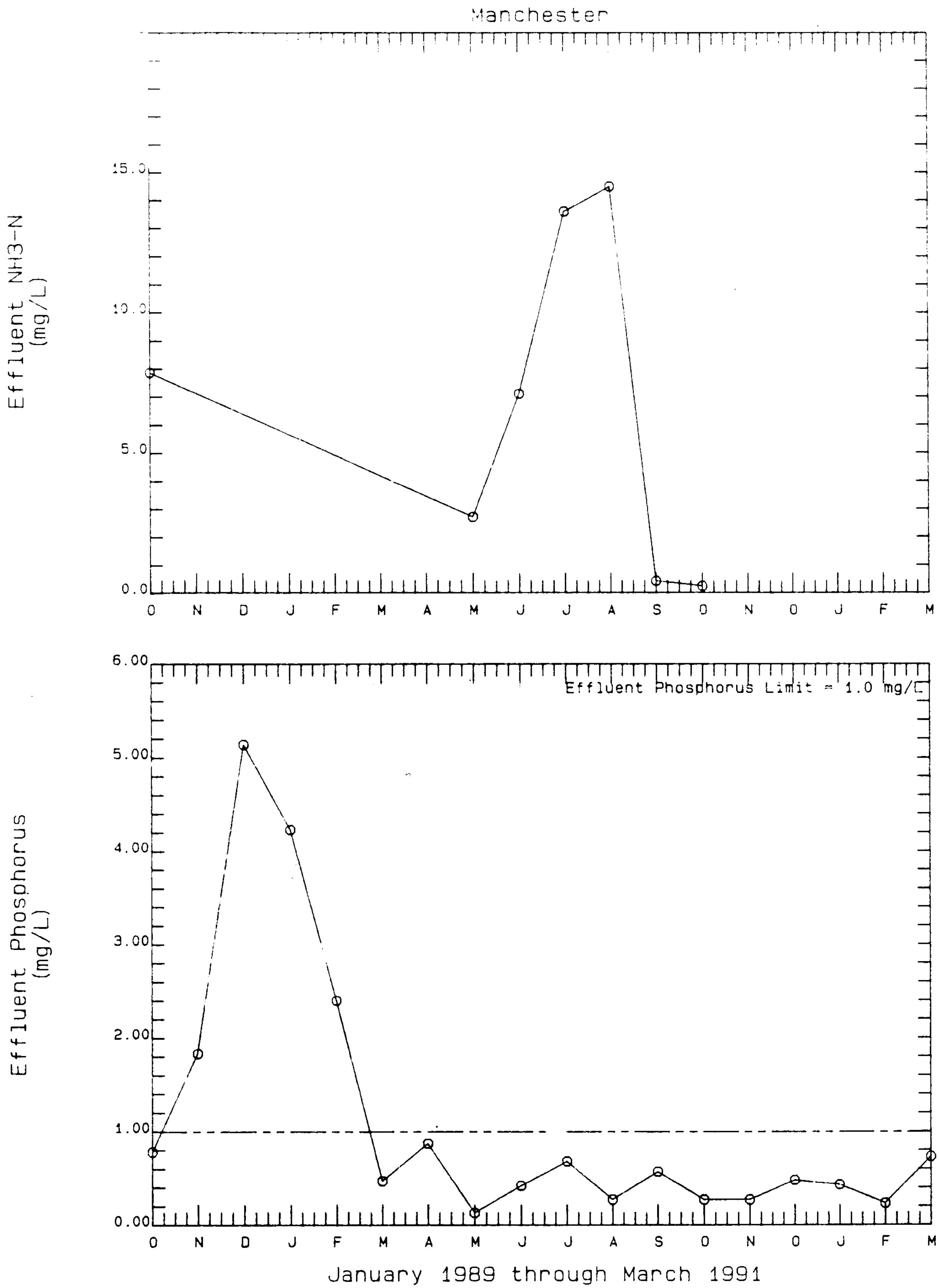
GRUNDY CENTER, IOWA
Performance Data

Date	Flow		Influent			Effluent				Mixed Liquor						
Month/Year	Average (MGD)	Max. (MGD)	BOD_5 (mg/l)	TSS (mg/l)	NH_3-N (mg/l)	BOD_5 (mg/l)	TSS (mg/l)	NH_3-N (mg/l)	Temp. (F°/C°)	#1 MLSS (mg/l)	$Sett_{30}$ (ml/l)	SVI (ml/g)	#2 MLSS (mg/l)	$Sett_{30}$ (ml/l)	SVI (ml/g)	F/M (day^{-1})
12-89	0.330	0.464	249	201	27	2.9	6.5	0.73	54.0/12.2	2649	728	275	2271	742	327	0.071
1-90	0.316	0.345	257	191	23	2.4	6.3	0.22	51.7/10.9	2192	524	239	2202	599	272	0.078
2-90	0.325	0.393	230	201	24	4.2	12	0.28	50.0/10.0	2075	732	353	2244	666	297	0.073
3-90	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
4-90	0.406	0.809	264	218	19	0.9	12	4.6	53.0/11.7	1826	725	397	1915	521	272	0.122
5-90	0.863	2.285	133	157	8.9	5.5	12	5.3	56.0/13.3	2338	540	231	2513	500	199	0.10
6-90	1.125	3.168	85	201	7.0	3.2	9	1.5	60.0/15.6	2494	338	136	2802	398	142	0.077
7-90	0.954	3.845	173	158	10.0	4.9	7	0.07	66.0/18.9	2304	321	139	2795	311	133	0.131
8-90	0.753	1.476	118	115	7.0	1.0	3	0.16	66.0/18.9	2167	361	167	2839	471	166	0.075
9-90	0.518	0.726	172	158	10.0	2.6	7	0.18	66.8/19.3	2290	220	96	2611	279	107	0.077
10-90	0.369	0.491	213	180	17.5	2.9	5.8	0.16	63.0/17.2	1913	198	104	1932	197	102	0.087
11-90	0.366	0.410	249	180	20.0	2.8	3.2	0.45	59.0/15.0	2011	238	118	1930	241	125	0.099
Average	0.575	1.31	195	169	15.8	3.8	7.6	1.24	58.7/14.8	2205	447	203	2369	453	191	0.091

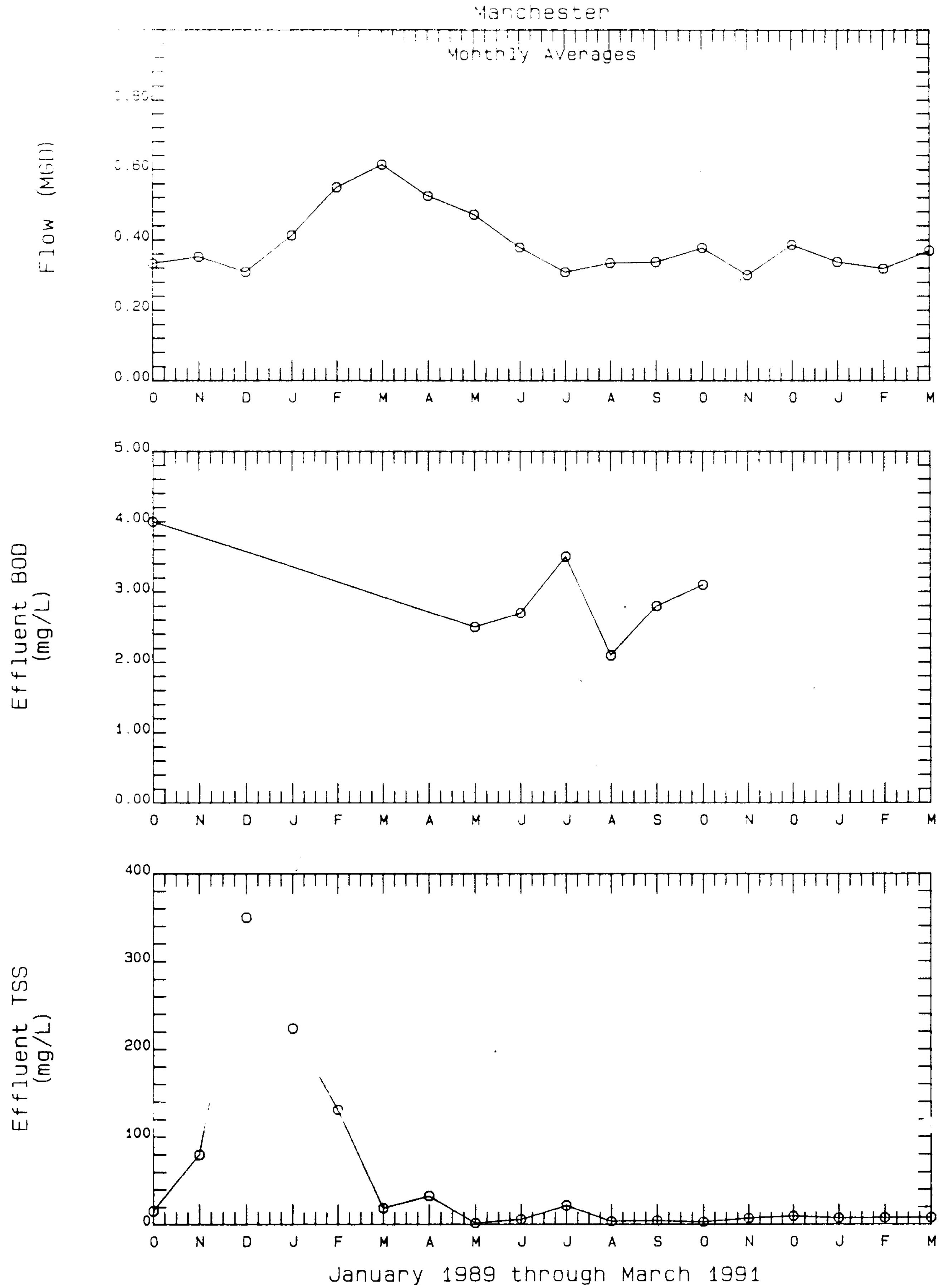
Manchester Monitoring Data
monthly averages taken from DMR profile

Month	Flow MGD	Effluent TSS mg/l	Effluent P mg/l	Effluent BOD mg/l	Effluent NH3-N mg/l(1)
Oct 1989	0.333	16.0	0.78	4.0	7.86
Nov 1989	0.352	80.0	1.83		
Dec 1989	0.309	350.0	5.14		
Jan 1990	0.414	224.0	4.23		
Feb 1990	0.551	131.0	2.40		
Mar 1990	0.615	19.0	0.47		
Apr 1990	0.526	32.9	0.87		
May 1990	0.473	1.8	0.13	2.5	2.71
Jun 1990	0.379	6.1	0.42	2.7	7.10
Jul 1990	0.309	22.0	0.68	3.5	13.60
Aug 1990	0.335	3.8	0.27	2.1	14.50
Sep 1990	0.338	4.6	0.57	2.8	0.43
Oct 1990	0.378	3.1	0.27	3.1	0.24
Nov 1990	0.301	7.6	0.27		
Dec 1990	0.387	10.0	0.48		
Jan 1991	0.338	7.5	0.43		
Feb 1991	0.319	7.9	0.23		
Mar 1991	0.370	8.1	0.73		
SUMMARY:					
Minimum	0.301	1.8	0.13	2.1	0.2
Maximum	0.615	350.0	5.14	4.0	14.5
Average	0.390	52.0	1.12	3.0	6.6
Limit			1.00		

NOTES:
1. Ammonia concentrations are monthly maxima (monthly averages were not available).



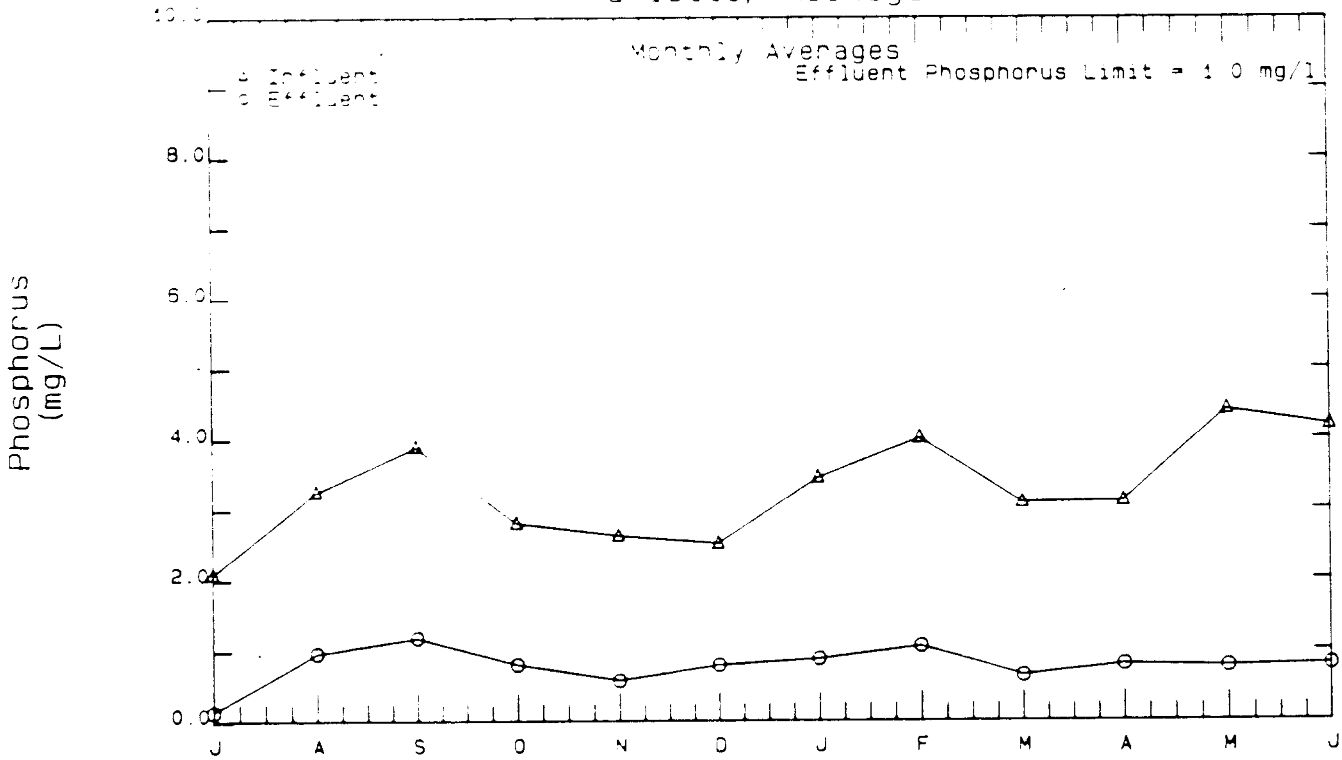
Manchester
Effluent NH3-N (mg/L)
15.0
10.0
5.0
0.0
O N D J F M A M J J A S O N D J F M
Effluent Phosphorus (mg/L)
Effluent Phosphorus Limit = 1.0 mg/L
6.00
5.00
4.00
3.00
2.00
1.00
0.00
O N D J F M A M J J A S O N D J F M
January 1989 through March 1991

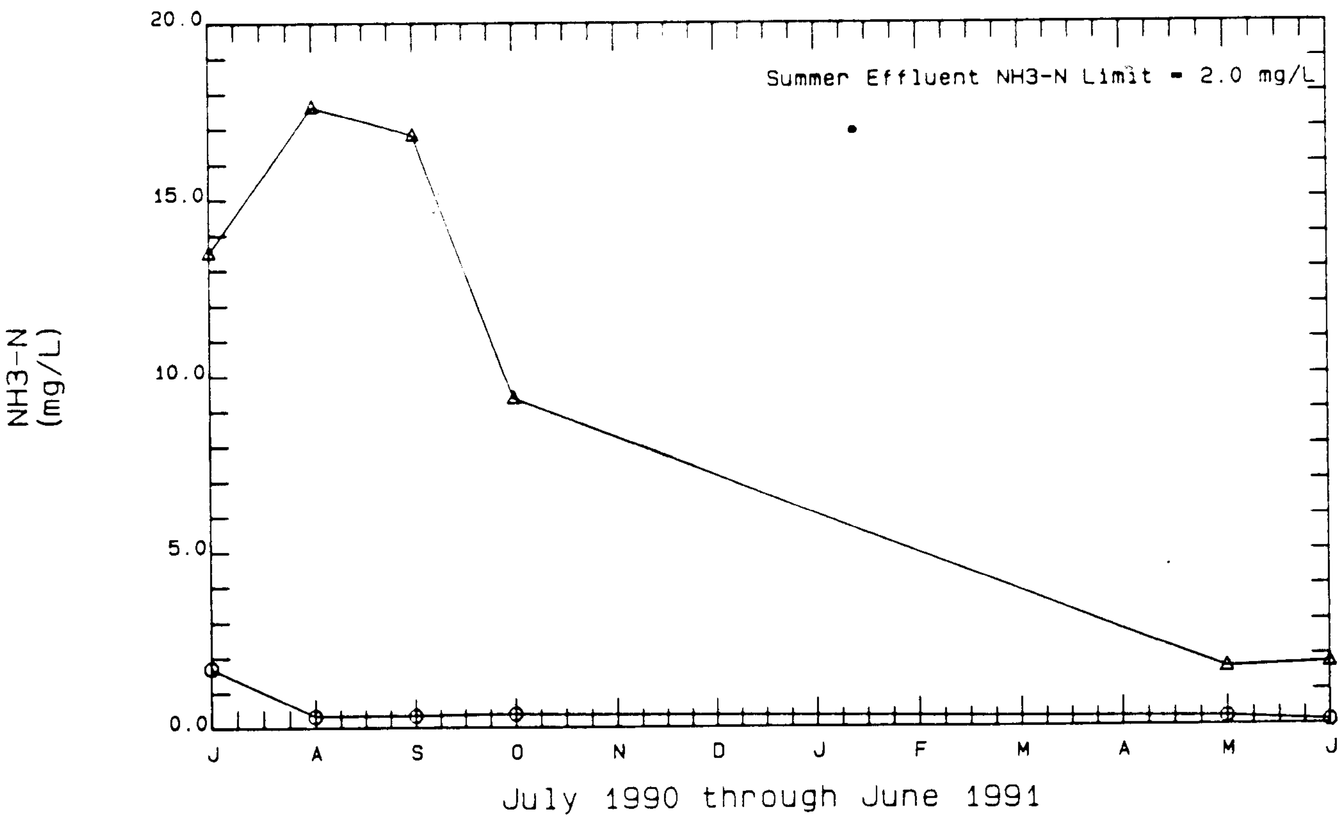

Manchester
Monthly Averages
Flow (MGD)
0.80
0.60
0.40
0.20
0.00
O N D J F M A M J J A S O N O J F M
Effluent BOD (mg/L)
5.00
4.00
3.00
2.00
1.00
0.00
O N D J F M A M J J A S O N O J F M
Effluent TSS (mg/L)
400
300
200
100
0
O N D J F M A M J J A S O N O J F M
January 1989 through March 1991

Marlette, Michigan WWTP - Monthly Average Data

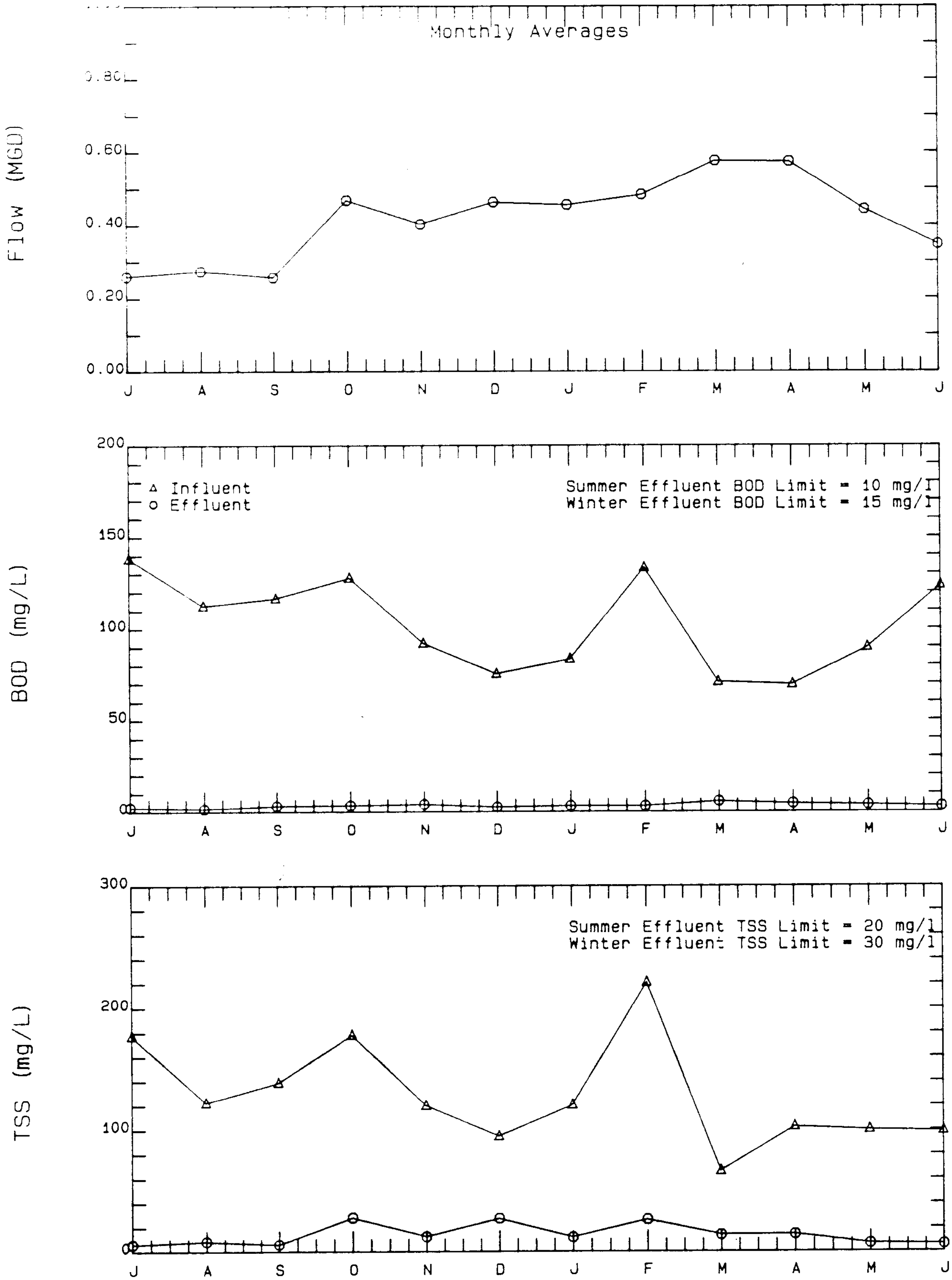
Month	Flow (MGD)	INF BOD (mg/L)	EFF BOD (mg/L)	INF TSS (mg/L)	EFF TSS (mg/L)	INF PHOS (mg/L)	EFF PHOS (mg/L)	INF NH3-N (mg/L)	EFF NH3-N (mg/L)
790	0.259	138.38	2.51	177.3	6.1	2.07	0.13	13.48	1.7
890	0.274	112.47	1.71	122.3	8.8	3.25	0.96	17.62	0.32
990	0.257	116.74	3.39	138.8	6	3.89	1.18	16.81	0.33
1090	0.469	127.76	3.63	178	28.2	2.8	0.8	9.34	0.37
1190	0.403	92.06	4.26	119.8	12.5	2.62	0.57		
1290	0.464	75.22	2.72	94.9	27.5	2.51	0.79		
191	0.456	83.36	3.32	120.4	12	3.45	0.88		
291	0.484	133.15	3.2	220.9	26.6	4.01	1.06		
391	0.577	70.71	5.84	66	13.9	3.09	0.64		
491	0.575	69.36	4.54	102.6	14.4	3.11	0.8		
591	0.443	89.67	3.83	100	6.9	4.41	0.77	1.65	0.23
691	0.347	123.5	3	99	6.1	4.19	0.8	1.77	0.1

Marlette, Michigan





Marlette, Michigan



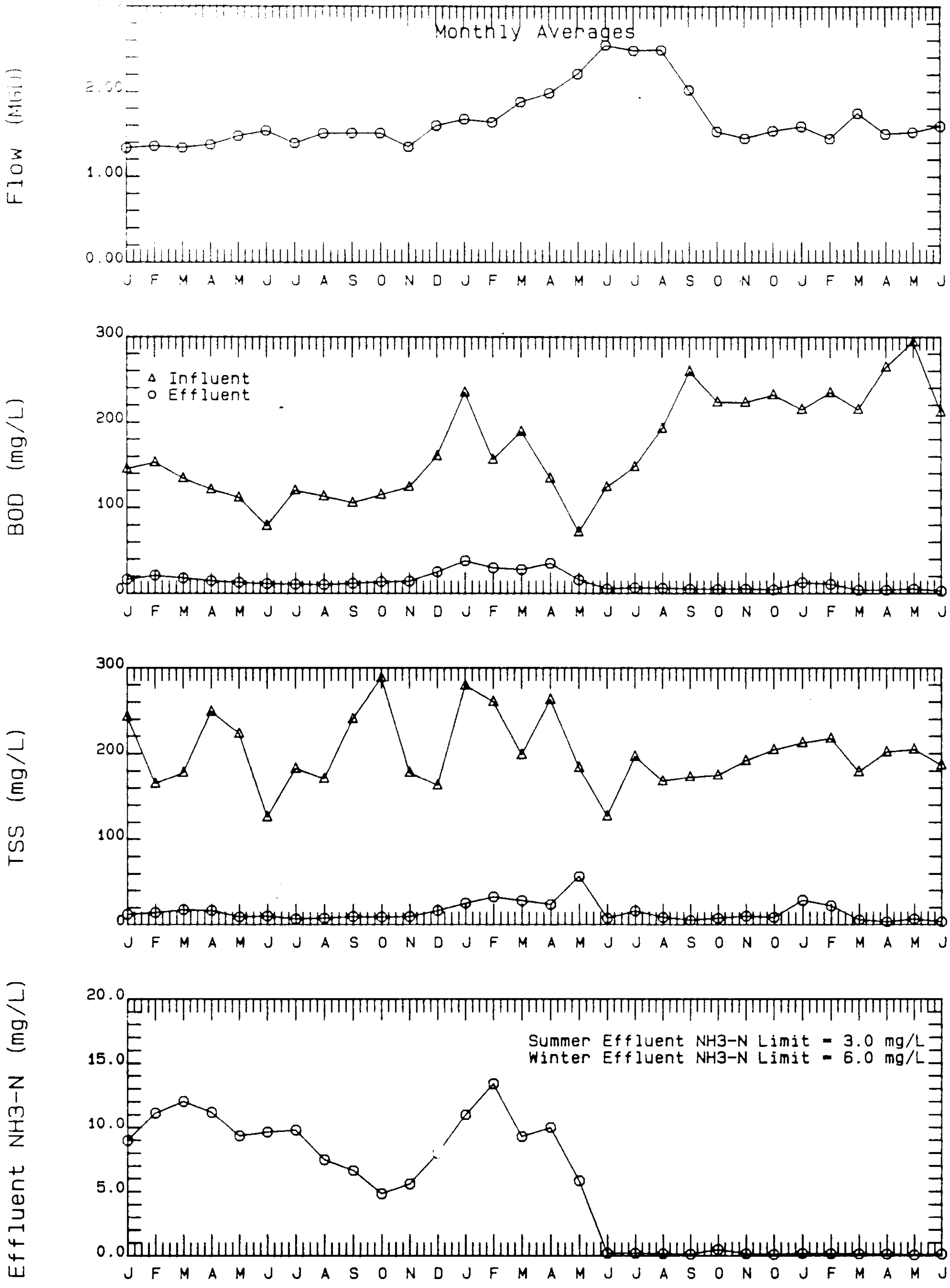
July 1990 through June 1991

MCPHERSON, KANSAS

Monthly Averages

Date	Flow MGD	Influent BOD (mg/L)	Influent TSS (mg/L)	Effluent BOD (mg/L)	Effluent TSS (mg/L)	Effluent NH3-N (mg/L)
690	2.545	124.0	127.0	5.5	8.0	0.20
790	2.481	148.0	197.0	7.0	16.5	0.20
890	2.488	193.0	168.0	6.5	9.0	0.17
990	2.024	259.5	173.0	5.5	5.5	0.13
1090	1.533	223.5	175.0	5.0	8.0	0.50
1190	1.452	223.0	192.0	5.5	10.5	0.16
1290	1.541	232.0	204.5	4.5	9.0	0.11
191	1.593	215.0	212.5	13.0	29.0	0.18
291	1.448	234.5	217.5	11.0	22.5	0.16
391	1.749	215.0	179.0	4.0	6.0	0.14
491	1.504	264.5	202.0	4.0	3.5	0.13
591	1.526	294.0	205.0	5.5	7.0	0.06
691	1.596	212.0	187.0	3.0	3.5	0.12
/*						
AVG =	1.806	218.3	187.7	6.2	10.6	

McPherson, Kansas



January 1989 through June 1991

MIFFLINBURG, PENNSYLVANIA

PERFORMANCE DATA

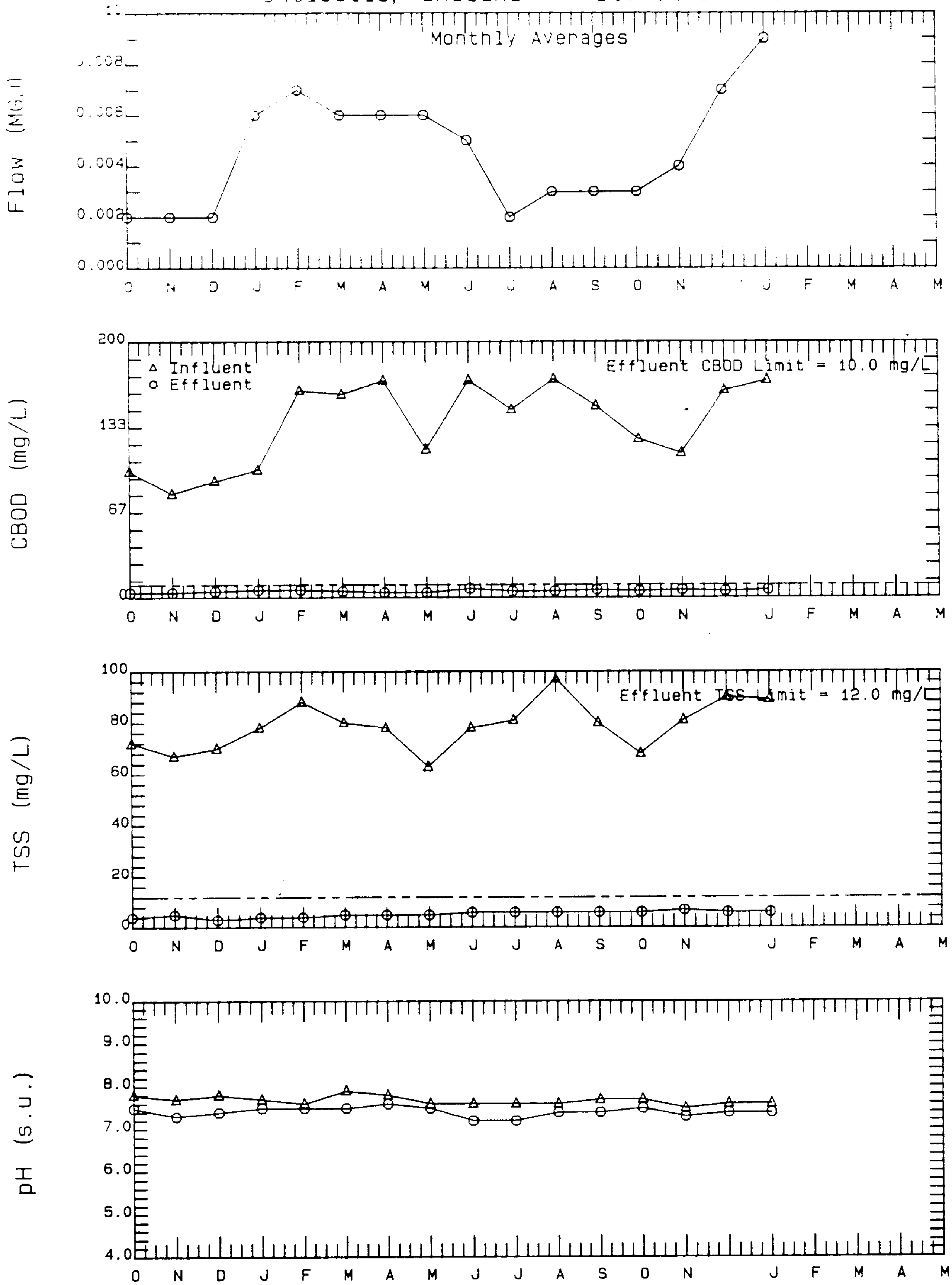
DATE	FLOW		INFLUENT		EFFLUENT				MIXED LIQUOR				
MO./YR.	AVERAGE (MGD)	MAX.DAY (MGD)	BOD_5 (mg/l)	NH_3-N (mg/l)	BOD_5 (mg/l)	TSS (mg/l)	NH_3-N (mg/l)	Temp. (F^o/C^o)	#1MLSS (mg/l)	SVI (ml/g)	#2MLSS (mg/l)	SVI (ml/g)	F/M (day^{-1})
10/88	0.55	1.26	110	--	3.8	13.0	0.76	58.9/14.9	1289	85	2089	95	0.033
11/88	0.65	1.33	120	--	15.5	15.6	0.25	56.1/13.4	1250	93	2491	94	0.038
12/88	0.50	0.91	170	9.1	23.2	19.2	0.30	51.6/10.9	1655	106	2073	143	0.042
1/89	0.64	1.14	135	9.1	22.3	20.5	0.40	48.2/9.0	2133	206	2400	234	0.035
2/89	0.54	0.90	178	9.3	28.8	10.9	0.78	49.9/9.9	2031	246	2846	249	0.036
3/89	0.66	1.60	101	13.1	15.6	14.3	0.38	50.3/10.2	1539	150	2958	259	0.027
4/89	0.60	1.11	154	8.4	11.8	13.8	0.46	52.9/11.6	1550	194	2514	267	0.042
5/89	1.08	2.44	91	5.7	16.3	13.1	0.60	56.3/13.5	1733	184	2364	162	0.044
6/89	0.70	1.43	95	6.9	13.4	9.9	0.39	60.1/15.6	2460	127	2720	122	0.024
7/89	1.06	2.45	63	6.8	10.5	9.0	0.38	64.2/17.9	2352	91	2400	111	0.026
8/89	0.62	1.93	86	6.6	11.0	12.0	0.28	65.8/18.8	1855	72	2300	91	0.023
9/89	0.54	0.76	88	7.8	11.2	9.0	0.30	63.4/17.4	2525	84	2543	92	0.017
10/89	0.84	2.35	92	6.7	14.5	9.9	0.32	59.6/15.3	2642	120	3117	118	0.025
11/89	0.57	1.48	75	7.3	12.3	3.9	0.26	55.0/12.8	2883	92	3218	106	0.013
12/89	0.49	0.68	106	7.9	10.4	4.5	0.30	48.0/8.9	2760	152	3186	118	0.016
1/90	0.56	1.42	95	7.7	8.8	9.3	0.49	50.4/10.2	2982	220	3182	166	0.016
2/90	0.77	1.14	116	9.5	8.5	10.2	0.71	49.9/9.9	2436	218	2683	227	0.032
3/90	0.62	0.86	109	6.3	10.1	9.5	1.12	51.6/10.9	2783	226	2833	243	0.022
4/90	0.64	1.05	102	8.0	8.5	6.8	0.30	53.6/12.0	2517	246	2633	261	0.023
5/90	0.76	1.46	72	5.6	7.1	7.5	0.34	56.9/13.8	2777	214	2700	250	0.018
6/90	0.65	0.99	115	11.1	6.5	6.7	0.54	61.2/16.2	2433	182	2546	219	0.027
7/90	0.61	1.15	111	6.0	12.8	7.7	0.17	65.3/18.5	2800	187	3111	196	0.021
8/90	0.87	2.62	93	10.8	7.4	6.8	0.29	65.0/18.4	2554	229	2787	250	0.028
9/90	0.73	1.33	115	14.1	8.9	5.8	0.29	63.6/17.6	2818	263	3140	240	0.026
10/90	1.19	2.68	65	6.7	10.7	7.9	0.10	59.9/15.5	2382	238	2833	252	0.027
11/90	0.76	1.69	113	7.5	9.5	8.0	0.15	56.7/13.7	2542	232	2933	217	0.029
12/90	0.95	1.57	97	7.2	8.0	6.4	0.13	53.9/12.2	2262	287	2400	282	0.036
1/91	1.02	2.12	81	5.5	8.3	6.7	0.34	49.0/9.4	2267	244	2333	280	0.033
2/91	0.80	1.45	80	10.1	7.8	6.0	0.89	48.9/9.4	2283	224	2392	225	0.025
3/91	0.85	1.37	118	13.9	7.1	10.9	0.51	52.1/11.2	2440	243	2418	223	0.038
Average	0.73	1.49	105	7.8	11.7	9.8	0.42	55.9/13.3	2298	182	2671	193	0.028
Design	0.90	2.30	200	25.0	20/25	30.0	3.0/9.0	50.0/10.0 Minimum	3330	---	3330	---	0.049

MONTICELLO, INDIANA - WHITE OAKS RESORT

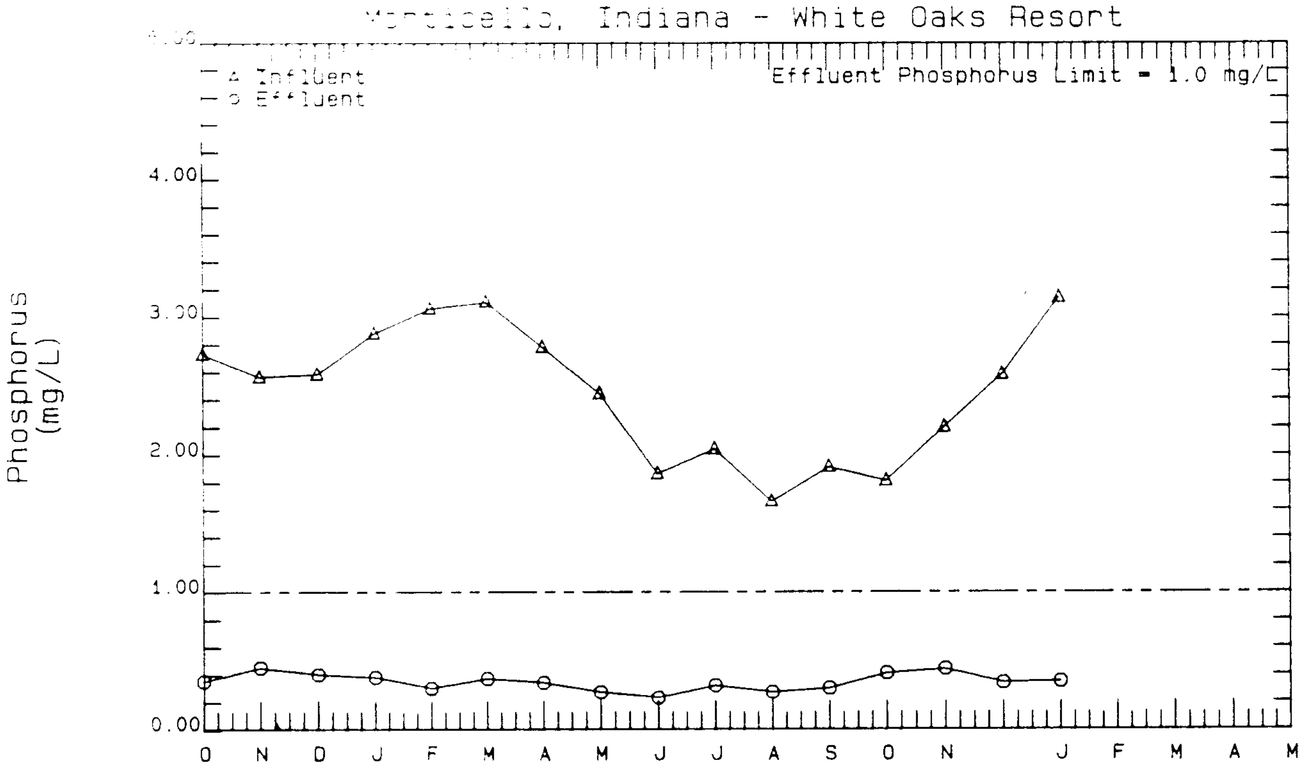
Monthly Averages

Date	Flow MGD	Influent CBOD (mg/L)	Effluent CBOD (mg/L)	Influent TSS (mg/L)	Effluent TSS (mg/L)	Influent pH	Effluent pH (mg/L)	Influent Ammonia (mg/L)	Effluent Ammonia (mg/L)	Influent Phosph (mg/L)	Effluent Phosph (mg/L)
1089	0.006	133	4	64	2	7.8	7.7	3.5	0.1	3.63	2.07
1189	0.002	117	3	70	2	7.7	7.6	3	0.4	3.09	0.59
1289	0.002	79	3	68	4	7.7	7.6	2.7	0.5	2.98	0.45
190	0.002	115	4	70	5	7.6	7.3	3.1	0.5	3.04	0.37
290	0.002	99	4	72	4	7.8	7.5	3.3	0.4	2.73	0.35
390	0.002	81	4	67	5	7.7	7.3	2.8	0.2	2.56	0.45
490	0.002	91	5	70	3	7.8	7.4	3.2	0.2	2.58	0.4
590	0.006	100	6	78	4	7.7	7.5	3	0.2	2.88	0.38
690	0.007	162	6	88	4	7.6	7.5	2.9	0.3	3.06	0.3
790	0.006	159	5	80	5	7.9	7.5	3.1	0.1	3.11	0.37
890	0.006	170	4	78	5	7.8	7.6	2.7	0.2	2.78	0.34
990	0.006	116	4	63	5	7.6	7.5	2.5	0.2	2.44	0.27
1090	0.005	170	7	78	6	7.6	7.2	2.8	0.1	1.86	0.23
1190	0.002	147	5	81	6	7.6	7.2	2.3	0.1	2.04	0.32
1290	0.003	171	5	97	6	7.6	7.4	2.2	0.1	1.66	0.27
191	0.003	150	6	80	6	7.7	7.4	2.7	0.2	1.91	0.3
291	0.003	124	5	68	6	7.7	7.5	2.9	0.2	1.81	0.41
391	0.004	113	6	81	7	7.5	7.3	3.1	0.3	2.2	0.44
491	0.007	162	5	90	6	7.6	7.4	2.9	0.6	2.58	0.34
591	0.009	170	6	89	6	7.6	7.4	6.9	0.8	3.14	0.35
/*											
SUM =	0.085	2629.000	97.000	1532.000	97.000	153.600	148.800	61.600	5.700	52.080	9.000
AVG =	0.004	131.450	4.850	76.600	4.850	7.680	7.440	3.080	0.285	2.604	0.450
STD =	0.002	31.085	1.062	9.173	1.352	0.098	0.132	0.929	0.188	0.527	0.380
MAX =	0.009	171.000	7.000	97.000	7.000	7.900	7.700	6.900	0.800	3.630	2.070
MIN =	0.002	79.000	3.000	63.000	2.000	7.500	7.200	2.200	0.100	1.660	0.230

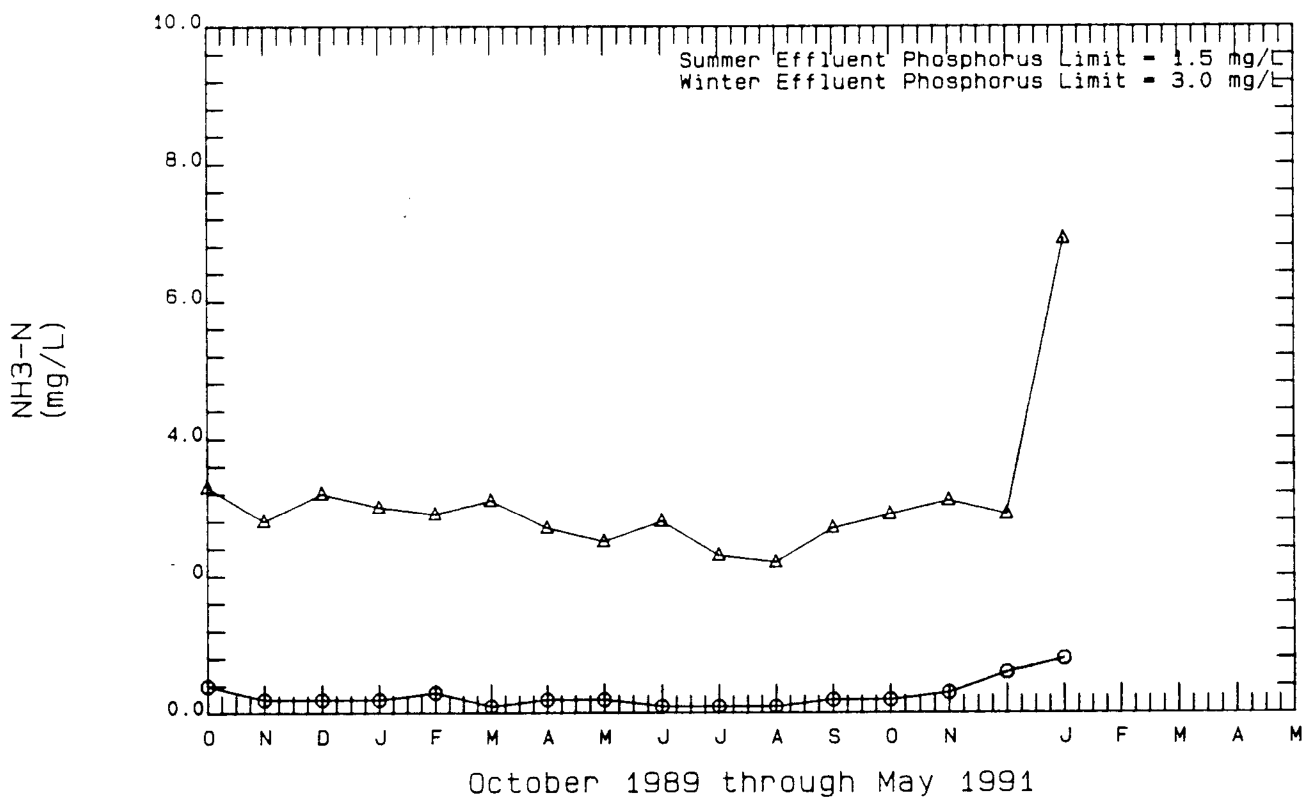
Monticello, Indiana - White Oaks Resort



October 1989 through May 1991



Monticello, Indiana - White Oaks Resort
Δ Influent
○ Effluent
Effluent Phosphorus Limit = 1.0 mg/L
Phosphorus (mg/L)
4.00
3.00
2.00
1.00
0.00
O N D J F M A M J J A S O N J F M A M



Summer Effluent Phosphorus Limit = 1.5 mg/L
Winter Effluent Phosphorus Limit = 3.0 mg/L
NH3-N (mg/L)
10.0
8.0
6.0
4.0
0.0
O N D J F M A M J J A S O N J F M A M
October 1989 through May 1991

CLOVER ESTATES MOBILE HOME PARK
Muskegon Heights, Michigan

DATE	INFLUENT				MIXED LIQUOR	EFFLUENT						
(Month/Year)	BOD_5 (mg/l)	TSS (mg/l)	NH_3-N (mg/l)	T-P (mg/l)	MLSS (mg/l)	BOD_5 (mg/l)	TSS (mg/l)	NH_3-N (mg/l)	NO_2-N (mg/l)	NO_3-N (mg/l)	Total Inorganic-N (mg/l)	T-P (mg/l)
1-88					3050	7	24	0.20	0.01	11.4	11.61	1.9
2-88					5333	4.9	11.4	0.20	0.01	11.2	11.41	2.0
3-88					6282	9.5	35.4	0.20	0.01	6.3	6.51	3.0
4-88					4428	4.6	21.9	0.20	0.01	3.1	3.31	1.7
5-88					2845	5.3	11.9	0.20	0.02	3.6	3.82	1.7
6-88					1978	5.1	14.1	0.20	0.01	3.3	3.51	
7-88					3185	6.0	23.4	0.20	0.01	2.6	2.81	
8-88					2556	5.5	13.5	0.20	0.01	3.1	3.31	
9-88					3538	6.4	9.1	0.20	0.02	2.7	2.92	3.2
10-88					4725	5.1	13.9	0.20	0.01	2.3	2.51	1.5
11-88					4430	4.6	7.0	0.20	0.01	3.4	3.61	
12-88					4713	4.3	7.0	0.20	0.01	2.9	3.11	
1-89					3793	8.9	22.8	0.20	0.01	4.1	4.31	
2-89					3428	12.2	31.3	0.20	0.01	3.9	4.11	
3-89					3786	8.2	13.6	0.56	0.19	3.9	4.65	
4-89	167	45	25.5	5.6	3515	9.8	8.3	1.10	0.25	5.0	6.35	1.4
5-89	223	228	12.5	3.1	2640	10.6	15.4	2.04	0.15	2.6	4.79	2.1
6-89	165	124	25.5	4.1	2793	10.8	11.3	1.43	0.11	2.2	3.74	1.2
7-89					2605	7.5	12.8	0.20	0.04	1.2	1.44	

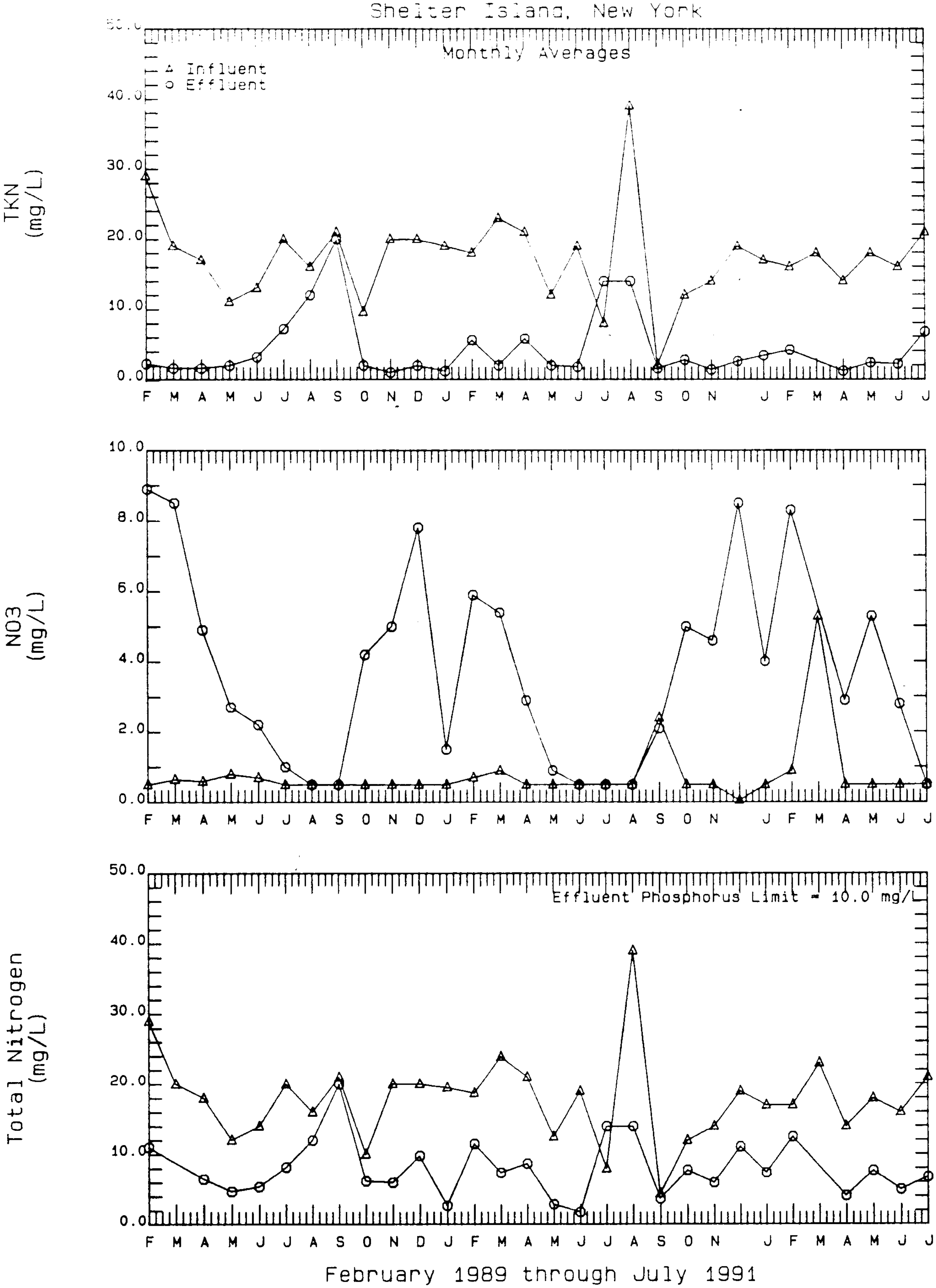
CLOVER ESTATES

Muskegon Heights, Michigan

DATE	INFLUENT				MIXED LIQUOR	EFFLUENT						
(Month/Year)	BOD_5 (mg/l)	TSS (mg/l)	NH_3-N (mg/l)	T-P (mg/l)	MLSS (mg/l)	BOD_5 (mg/l)	TSS (mg/l)	NH_3-N (mg/l)	NO_2-N (mg/l)	NO_3-N (mg/l)	Total Inorganic-N (mg/l)	T-P (mg/l)
8-89					2078	4.4	4.8	0.20	0.15	1.6	1.95	
9-89												
10-89												
11-89												
12-89												
1-90					5115	28.2	36.7	5.20	0.58	2.0	7.78	2.4
2-90					3670	32.1	50.9	0.20	1.10	1.6	2.90	0.20
3-90					3096	7.9	6.5	0.42	0.17	4.1	4.69	1.80
4-90					3315	7.4	16.6	3.03	0.39	0.8	4.22	
5-90					3182	1.8	3.2	0.20	0.12	2.1	2.42	
6-90					2573	9.1	33.7	0.20	0.07	1.8	2.07	
7-90					2113	13.7	23.2	1.70	0.79	1.2	3.69	
8-90					2099	8.1	99.3	0.20	0.04	1.8	2.04	
9-90					1910	11.3	9.5	0.20	0.12	1.7	2.02	
10-90					2133	11.5	14.0	0.20	0.16	2.9	3.26	
Average	185	132	21.2	4.3	3364	9.1	20.2	0.67	0.15	3.4	4.16	1.85
Design	200	200	22		3600	30	30				5.0	

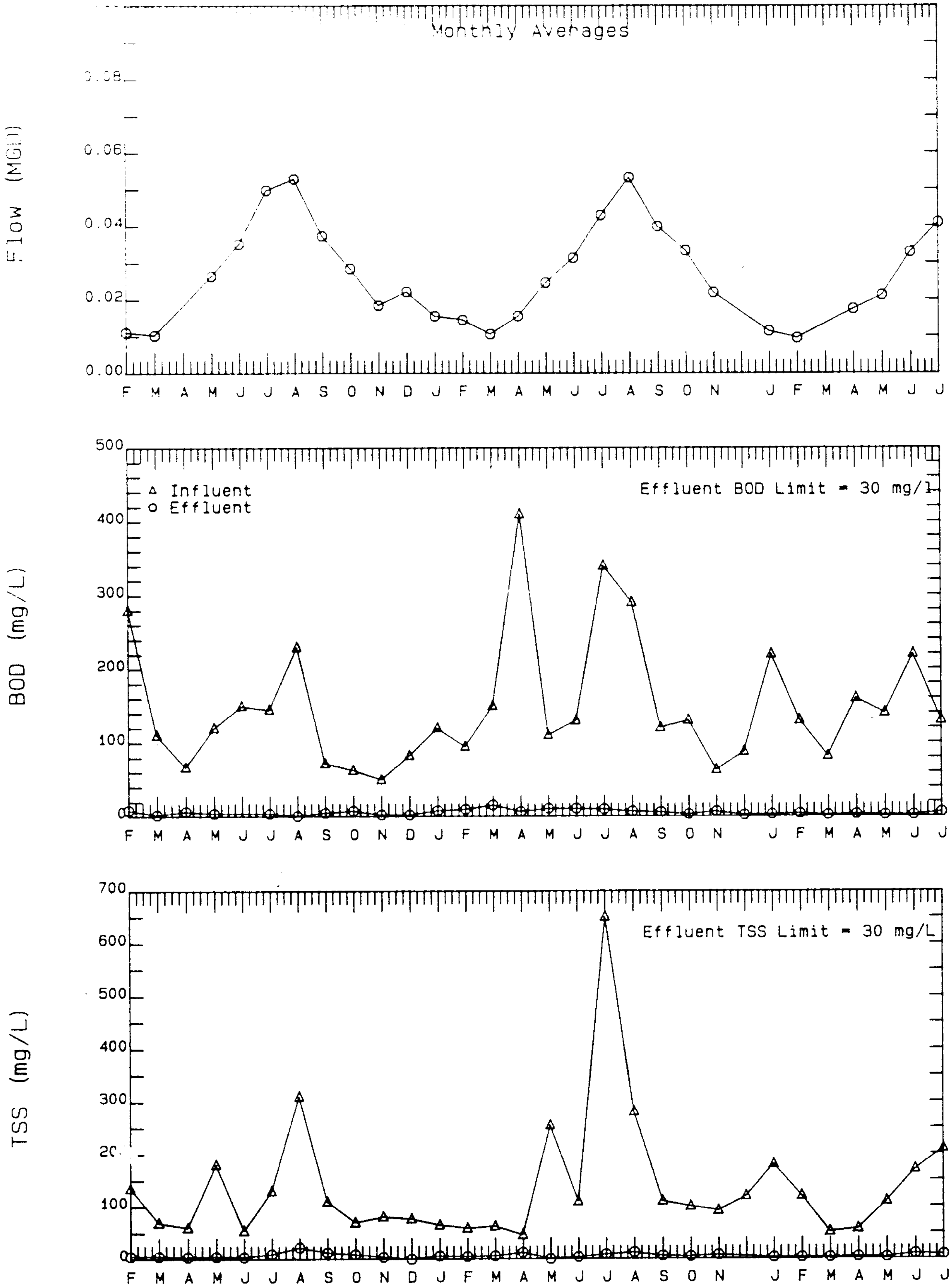
Shelter Island, New York WWTP Monthly Average Data

Month	Flow (MGD)	INF BOD (mg/L)	EFF BOD (mg/L)	INF TSS (mg/L)	EFF TSS (mg/L)	INF TKN (mg/L)	EFF TKN (mg/L)	INF NO3 (mg/L)	EFF NO3 (mg/L)	INF Tot N (mg/L)	EFF Tot N (mg/L)
189	0.0113	100	1	55	-4	21	1.8	-0.5	2.5		4.3
289	0.0111	280	8.7	135	-5	29	2.2	-0.5	8.9	29	11
389	0.0103	110	2.2	69	-5	19	1.6	0.65	8.5	20	
489		67	7.2	60	4	17	1.6	0.6	4.9	18	6.5
589	0.0265	120	4.3	180	-5	11	2	0.8	2.7	12	4.7
689	0.0352	150		54	-4	13	3.2	0.7	2.2	14	5.4
789	0.0499	145	4.2	130	10	20	7.2	-0.5	1	20	8.2
889	0.053	230	1	310	23	16	12	-0.5	-0.5	16	12
989	0.0374	72	5.3	110	13	21	20	-0.5	-0.5	21	20
1089	0.0285	63	8	70	9	9.6	2	0.5	4.2	10	6.2
1189	0.0185	50	2.5	81	4	20	1	-0.5	5	20	6
1289	0.0222	83	2.3	77	-0.01	20	2	-0.5	7.8	20	9.8
190	0.0155	120	8.3	65	6	19	1.2	0.5	1.5	19.5	2.7
290	0.0145	95	10	59	5	18	5.6	0.7	5.9	18.7	11.5
390	0.0106	150	16	63	6	23	2	0.9	5.4	23.9	7.4
490	0.0155	410	7	46	-13	21	5.8	-0.5	2.9	21	8.7
590	0.0246	110	11	255	-0.6	12	2	0.5	0.9	12.5	2.9
690	0.0314	130	11	110	-4	19	1.8	-0.5	-0.5	19	1.8
790	0.043	340	10	650	9	8	14	-0.5	-0.5	8	14
890	0.0533	290	7	280	13	39	14	-0.5	-0.5	39	14
990	0.0399	120	6	110	6	2	1.6	2.4	2.1	4.4	3.7
1090	0.0333	130	3	100	5	12	2.8	-0.5	5	12	7.8
1190	0.0219	63	7	92	8	14	1.4	-0.5	4.6	14	6
1290		88	-2	120		19	2.6	-0.05	8.5	19	11.1
191	0.0114	220	3	180	-3	17	3.4	-0.5	4	17	7.4
291	0.0095	130	4	120	3	16	4.2	0.9	8.3	17	12.5
391		82	-2	51	-3	18		5.3		23	
491	0.0175	160	-3	57	-4	14	1.2	-0.5	2.9	14	4.1
591	0.0212	140	2	110	-3	18	2.4	-0.5	5.3	18	7.7
691	0.0329	220	-2	170	10	16	2.2	-0.5	2.8	16	5
791	0.041	130	6	210	8	21	6.8	-0.5	-0.5	21	6.8

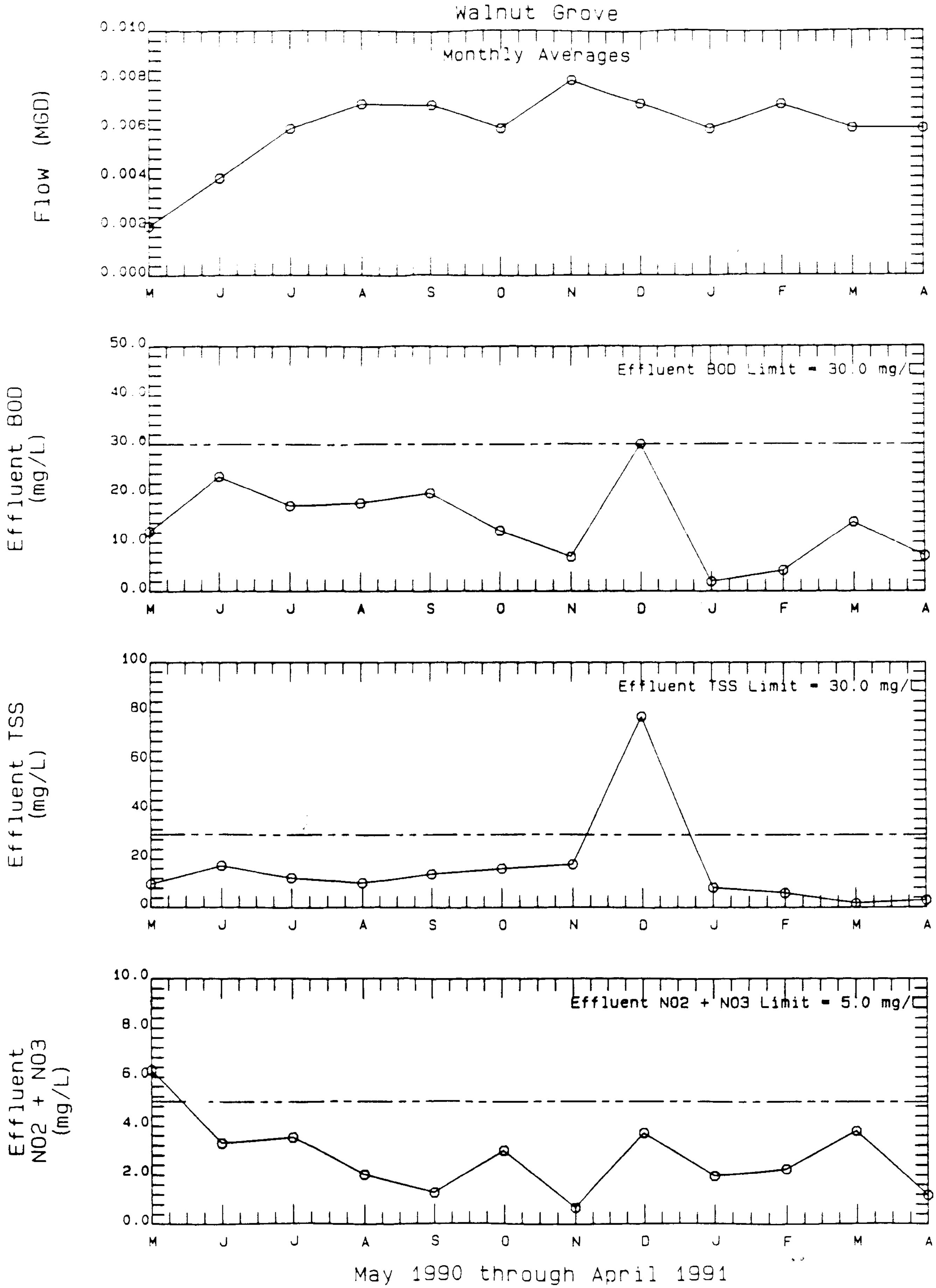


Shelter Island, New York
Monthly Averages
Δ Influent
o Effluent
TKN (mg/L)
NO3 (mg/L)
Total Nitrogen (mg/L)
Effluent Phosphorus Limit = 10.0 mg/L
F M A M J J A S O N D J F M A M J J A S O N J F M A M J J
February 1989 through July 1991

Shelter Island, New York



February 1989 through July 1991



Walnut Grove
Monthly Averages
Flow (MGD)
0.010
0.008
0.006
0.004
0.002
0.000
M J J A S O N D J F M A
Effluent BOD (mg/L)
Effluent BOD Limit = 30.0 mg/L
50.0
40.0
30.0
20.0
10.0
0.0
M J J A S O N D J F M A
Effluent TSS (mg/L)
Effluent TSS Limit = 30.0 mg/L
100
80
60
40
20
0
M J J A S O N D J F M A
Effluent NO2 + NO3 (mg/L)
Effluent NO2 + NO3 Limit = 5.0 mg/L
10.0
8.0
6.0
4.0
2.0
0.0
M J J A S O N D J F M A
May 1990 through April 1991

Windgap Municipal Authority
Windgap, Pennsylvania

Performance Data

Date	Flow		Influent			Effluent		
Month/Year	Average (MGD)	Maximum (MGD)	BOD_5 (mg/l)	TSS (mg/l)	NH_3-N (mg/l)	BOD_5 (mg/l)	TSS (mg/l)	NH_3-N (mg/l)
2/90	0.649	0.866	121	109	10.0	5.0	5.0	0.38
3/90	0.466	0.621	146	104	18.0	7.0	4.0	0.60
4/90	0.577	0.918	111	92	10.0	4.0	5.0	0.22
5/90	0.843	1.979	123	116	8.0	9.0	14.0	0.74
6/90	0.568	0.783	108	102	12.0	7.0	7.0	0.83
7/90	0.510	1.036	127	58	20.0	6.0	2.0	0.85
8/90	0.533	0.801	183	136	10.0	8.0	4.0	0.72
9/90	0.437	0.588	255	182	15.0	8.0	3.0	0.50
10/90	0.447	0.873	264	278	13.0	5.0	3.0	0.43
Average Values	0.559	0.941	160	131	12.9	6.6	5.2	0.59
Design Values	1.0	2.0	175	175	25	10-S 20-W	30	2.0-S 6.0-W

Walnut Grove Monitoring Data
monthly averages taken from DMR profile

Month	Flow MGD	Effluent BOD mg/l	Effluent TSS mg/l	Effluent NO2 & NO3 mg/l
May 1990	0.002	12.2	9.6	6.29
Jun 1990	0.004	23.4	17.1	3.31
Jul 1990	0.006	17.4	12.2	3.54
Aug 1990	0.007	17.9	10.0	2.02
Sep 1990	0.007	20.0	13.8	1.26
Oct 1990	0.006	12.3	16.0	3.01
Nov 1990	0.008	7.0	17.7	0.68
Dec 1990	0.007	30.0	78.0	3.70
Jan 1991	0.006	2.0	8.3	1.96
Feb 1991	0.007	4.3	6.0	2.25
Mar 1991	0.006	14.1	1.7	3.79
Apr 1991	0.006	7.2	3.0	1.18
SUMMARY:				
Minimum	0.002	2.0	1.7	0.68
Maximum	0.008	30.0	78.0	6.29
Average	0.006	14.0	16.1	2.75
Limit	0.009	30.0	30.0	5.00

NOTES:
1. Plant began operation in May, 1990.
2. Flow rate is determined from the pump rate, through the use of a totalizer, or through the use of a continuous meter.
3. BOD, TSS and NO2 & NO3 concentrations are typically determined from one grab sample per month.